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NKK's Dioxin Removal Techniques

Yo Osada*, Keizou Hamaguchi**,
Susumu Ayukawa*** and Takashi Yokoyama****

Limits for dioxin emissions from municipal solid waste (MSW) incinerator flue gas were tightened to below 0.1 ng-TEQ/N m³ for all newly-constructed incinerators by guidelines from the Japanese Ministry of Health and Welfare in January 1997. NKK meets the new regulations by combining techniques such as a low temperature bag filter; powdered, activated carbon injection into the bag filter; a moving bed adsorption tower packed with activated carbon; and dioxins decomposition using a de-NOx catalyst under stable and complete combustion. This paper reviews the application and performance of these dioxin removal techniques.

1. Introduction

The amount of dioxins emitted from municipal solid waste incinerators is estimated to be about 80% of the total dioxins emissions in Japan. Measures for reducing dioxins from this source as strict as those currently used in Europe are urgently required[1].

Dioxins are readily re-synthesized even from very slight amounts of unburned substances (dioxin precursors) during cooling of the flue gas (at temperatures between 200 and 500 °C) in the presence of catalysts such as Cu or Fe compounds in the fly ash[2][3]. Although significant improvements have been made towards stable and complete combustion in an incinerator, a small degree of such precursors will remain in the flue gas. Accordingly, it is difficult to satisfy the severe target level of the new guideline of the Ministry of Health and Welfare of 0.1 ng-TEQ/N m³ for dioxins in the flue gas solely by improving combustion. Dioxin removal measures are also necessary in the flue gas treatment system.

Flue gas from municipal solid waste incinerator contains hazardous materials such as dusts, nitrogen oxides, hydrochloric acids, and sulfur oxides. Several removal processes for these materials have already been established, and systems that attain the respective allowable limits have already been installed. Common measures for removing dioxins in flue gas treatment systems are either to add a dioxins removal function to the existing systems for removing toxic materials or to operate the existing units under conditions that allows simultaneous removal of the toxic materials and dioxins. Since preceding papers already discussed in detail the suppression of dioxins generation at the combustion stage, this paper describes improvements in the efficiency for removing dioxins brought about by using a bag filter, activated carbon that adsorbs the dioxins, or de-NOx catalysts that decompose dioxins in the flue gas treatment system.

* Senior Research Engineer Dr. Environmental Plant System Lab, Engineering Research Center
** Research Engineer, Environmental Plant System Lab, Engineering Research Center
*** Environmental Plant Engineering and Design Dept.
**** Manager, Environmental Plant Engineering and Design Dept.

2. Removal of dioxins from flue gas

2.1 Removal of dioxins using bag filter

In the past, electrostatic precipitators were mainly used as a dust collector. However, the standard operating temperature of an electric precipitator was about 300 °C, which can often increase the quantity of dioxins generated by re-synthesis while the flue gas passes through the equipment. Thus, the old guideline of the Ministry of Health and Welfare that was imposed in December 1990 required dust collection at 200 °C or below. As a result, all of the incinerators built after the enforcement of the old guideline use a bag filter capable of high efficiency dust collection at low temperature. The new guideline has a stronger recommendation for shifting from a dust collector to a bag filter, and requires them to be operated at a low temperature.

Fig. 1 shows the relation between the dioxins removal efficiency and the operating temperature of the bag filter. The data was collected from municipal solid waste incinerators constructed by NKK. Decreasing the operating temperature of the bag filter increases the dioxins removal efficiency, resulting in 95% or more at 160 °C or below. When the inlet concentration is 2 ng-TEQ/N m^3 or less, an output of 0.1 ng-TEQ/N m^3 can be attained solely by using a bag filter at low temperature. However, since the flue gas of municipal solid waste incinerators contains 20 to 40% water, along with a slight amount of SOx, the prevention of acidic corrosion and ash adhesion must also be considered. Therefore, the practical lower limit of operation should be about 150 to 160 °C.

A bag filter is more advantageous for dioxins removal because of its high dust collection efficiency and its ability to remove submicron fly ash containing dioxins. Furthermore, gas phase dioxins can be removed by being attracted to the surface of fly ash, while the flue gas passes through the dust deposit layer on the surface of the filter fabric. We made experiments to examine the effects of the dust deposit layer on dioxin removal. The temperature of the flue gas at the bag filter inlet was maintained at 230 °C, which is a rather high operating temperature, and the thickness of the dust layer deposited onto the surface of the filter fabric was varied by changing the air blowing conditions for the deposited ash. The dioxins concentration at the inlet and outlet of the bag filter were then determined.

Fig. 2 shows the relation between the dioxins removal efficiency and the pressure difference across the bag filter. This pressure difference is an index of the thickness of dust deposit layer. The dioxins removal efficiency improves with an increase in the pressure difference. Consequently, reducing the operating temperature and controlling the pressure difference across the bag filter should be important factors for bag filter operation to achieve high dioxins removal efficiency.

2.2 Dioxins removal by adsorption using injection of powdered activated carbon

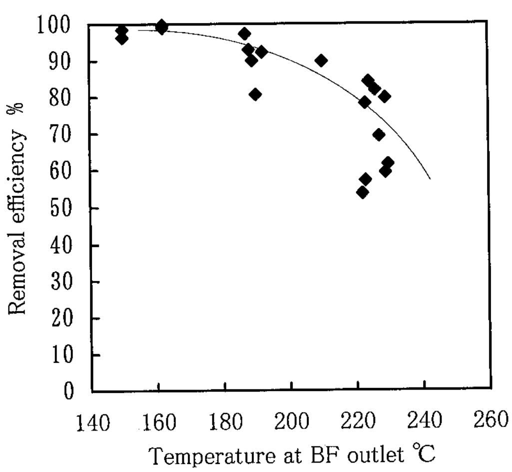

Fig. 1 Bag filter temperature vs. dioxins removal efficiency

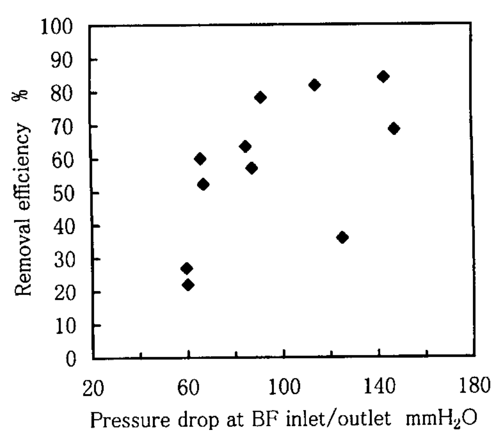

Fig. 2 Pressure difference between inlet and outlet of bag filter vs. dioxins removal efficiency

Dioxins and furan are compounds with four substituted chlorine atoms. This structure is an index for toxicity evaluation. These compounds have a vapor pressure as high as that of mercury, although their boiling point is 400 °C or more[4]. Accordingly, these compounds in the waste incinerator flue gas should be present in the gaseous phase, even when the flue gas is about 200 °C, which is within the dust collection temperature range[5].

Fig. 3 shows the relation between the concentration of total organic carbon in the fly ash and the dioxins removal efficiency at 230 °C. As shown in the figure, an increased content of organic carbons in the fly ash increases the removal efficiency. The relation suggests that slight amounts of organic carbons or unburned soot in the fly ash contribute to dioxins removal as a dioxins adsorbent. While unburned carbons in the fly ash are a dioxins starting material when the fly ash temperature is around 300 °C (de novo reaction)[2], they should serve as a dioxins adsorbent when the temperature is below 300 °C. Therefore, although establishing a complete combustion state reduces the amount of dioxins, it adversely affects the removal of dioxins in bag filters because it also reduces the unburned carbon and thereby its capabilities as an adsorption medium. Therefore, an effective countermeasure is to inject powdered activated carbon as an adsorption medium into the flue gas duct before the bag filter. Since powder injection before the bag filter inlet is common practice (i.e., the injection of calcium hydroxide powder to remove hydrogen chloride), the injection system of powdered activated carbon is relatively easy to install in existing incinerators.

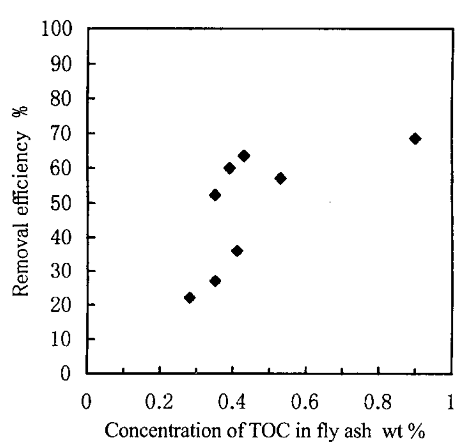

Fig. 3 Concentration of total organic carbon (TOC) in fly ash vs. removal efficiency of dioxins by bag filter

There are two methods for injecting activated carbon into flue gas. One is the injection of calcium hydroxide and activated carbon from separate silos in amounts corresponding to the concentration of dioxin and hydrogen chloride in the flue gas at the bag filter outlet. The other is the injection of premixed calcium hydroxide and activated carbon, which increases the removal efficiency owing to a more uniform distribution and prevents ignition. To combine the advantages of both methods, calcium hydroxide with a high concentration of activated carbon is prepared by mixing in specified quantities, and the mixture is further blended while it is transferred in the conveyer pipe, before being injected into the flue gas corresponding to the outlet concentration of their target ingredients. The effect of this method on removing dioxins was then tested.

The activated carbon used for the test was derived from coconuts shells and had a specific surface area of 1030 m^2/g. A specified quantity of the activated carbon and JIS Special Grade calcium hydroxide was charged into a calcium hydroxide transfer vehicle. The mixture was then further agitated in a tank, using compressed air to prepare the injection material. The test was carried out in a continuous-feed stoker incinerator ("A" plant; 200 t/d) and a semi-continuous-feed stoker incinerator ("B" plant; 25 t/d)[6].

Since "A" plant uses an ACC (automatic combustion controlling) system, the incineration is stable, and inherently induces fewer sudden CO spikes. In this test, the control was more strict for incineration in the plant through the use of manual operation to ensure CO peaks of 10 ppm or less in the flue gas during the observation period. As a result, the dioxins concentration at the boiler outlet was suppressed to 1 ng-TEQ/N m^3 or less except on one observed run. The concentration of dioxins at the outlet of the bag filter was also low, at around 0.1 ng-TEQ/N m^3, without the injection of activated carbon, in spite of the rather high temperature of 200 °C at the bag filter inlet. Also, the HCl concentration was kept below the standard limit of 50 ppm.

Fig. 4 shows the relation between the quantity of activated carbon injected, the dioxins concentration at the bag filter outlet, and the dioxins removal efficiency across the bag filter (determined from the difference in the dioxins concentration between the inlet and outlet of the bag filter). The injection of activated carbon decreased the dioxins concentration at the bag filter outlet to 0.04 ng/N m^3 or less in all of the measurements. Four of the observed runs gave extremely low levels of 0.01 ng/N m^3 or less, although there was some variation, and provided 95% or higher dioxins removal efficiency by injecting just 0.1 g/N m^3 of activated carbon.

Since the gas cooling system of the "B" plant has a chamber on the top of the one-way flue, secondary combustion was unstable, and the furnace outlet temperature and the CO concentration fluctuated. Thus, the dioxins concentration at the inlet of the bag filter was rather high, ranging from 1.6 to 9.9 ng-TEQ/N m^3. **Fig. 5** shows the relation between the quantity of activated carbon injected, the dioxins concentration at the bag filter outlet, and the dioxins removal efficiency across the bag filter. The concentration of dioxins at the outlet of the bag filter was 1.6 and 0.71 ng-TEQ/N m^3 when activated carbon was not injected. However, the injection of activated carbon significantly decreased the TEQ concentration, with some data giving less than 0.1 ng-TEQ/Nm^3 at an injection rate of 0.1 g/N m^3. A value of 0.1 ng-TEQ/N m^3 or less was consistently obtained, except for a single run, by injecting activated carbon at 0.3 g/N m^3 or more. This level is as low as that obtained by the fully-continuous incinerator of "A" plant.

These tests resulted in the following findings. When the dioxins concentration at the dust collector inlet is as low as several nano-grams of TEQ/N m^3, as seen in a fully-continuous incinerator, the quantity of activated carbon that needs to be injected is no more than 0.1 g/N m^3. For a semi-continuous, or batch-wise incinerator, the injection of approximately 0.3 g/N m^3 of activated carbon provides a high removal efficiency that is equal to that attained in fully-continuous incinerators. By injecting calcium hydroxide, the dust concentration reaches a level of 3 to 6 g/N m^3. However, since the amount of activated carbon in the fly ash is several percentage points for the case of a fully-continuous incinerator, the properties of fly ash are not significantly affected by such injection.

2.3 Removal of dioxins by adsorption tower packed with activated carbon

Another method for removing dioxins is to use an adsorption tower packed with an activated carbon adsorbent. In this method, the flue gas is passed through the tower after dust collection to further remove dioxins by adsorption. This method has extensive commercial experience in Europe as a more reliable dioxins removal method than the powdered activated carbon injection method, although one drawback is that the facility is somewhat large.

For the packed tower system, NKK introduced the technology of Wärmetechnik Kraftwerketechnik Verfahrenstechnik (WKV) system from a German company and confirmed the performance using actual plant flue gas[7]. In this system, after dust is removed in a dust collector, the flue gas is introduced into the bottom of a moving bed of the tower to put in contact with activated carbon adsorbents, which allows the adsorbents to absorb the dioxins for removal. The ad-

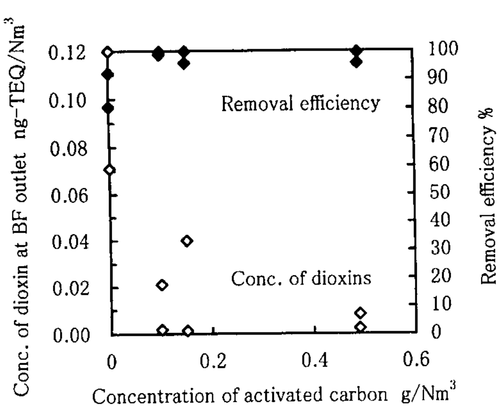

Fig. 4 Effects of activated carbon injection on dioxins removal (plant A; fully-continuous)

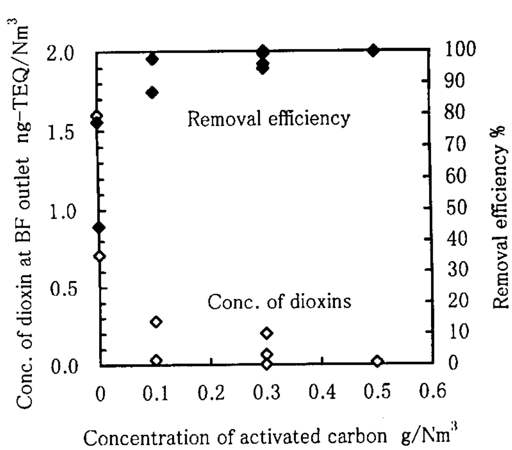

Fig. 5 Effects of activated carbon injection on dioxins removal (plant B; semi-continuous)

sorption tower has an internal structure that allows efficient contact between the flue gas and the adsorbents and has a bottom configuration that allows degraded adsorbents to be successively withdrawn from the bottom when they have absorbed too much dioxins or become plugged with dust. The withdrawn adsorbents are discharged into the incinerator for disposal. The adsorbents are automatically supplied from a charging hopper on the top of the tower.

Fig. 6 shows the change in concentration of dioxins and mercury over time when flue gas was introduced into the adsorption tower at a temperature ranging from 130 to 150 °C and a space velocity (SV) of 800 h^{-1}. The tower was filled with cylindrically-formed, activated carbon (5 mm in diameter and 15 mm in length, with a specific surface area of 300 m^2/g). After 140 days of continuous operation, the removal efficiency of mercury decreased to some extent, but the concentration of dioxins was kept below 0.1 ng-TEQ/N m^3, and no degradation of dioxins removal performance was observed.

Although the system reliably decreases the dioxins concentration to 0.1 ng-TEQ/N m^3 or less, the apparatus tends to be somewhat large, and an auxiliary unit is required to prevent ignition. Consequently, the system is used for cases where an outlet dioxins concentration of 0.05 ng-TEQ/N m^3 or less is required, which is more severe than typical cases.

2.4 Removal of dioxins by high performance catalytic de-NOx

Measures to reduce the emissions of nitrogen oxides from municipal solid waste incinerators often use either combustion control or non-catalytic de-NOx using injection of aqueous ammonia or aqueous urea into the incinerator. However, in the case of a severe requirement of 50 ppm or less, a honeycomb catalytic de-NOx unit using a titanium-vanadium oxide catalyst can be installed after the dust collector. In recent years, the titanium-vanadium oxide de-NOx catalyst has drawn attention because its ability to remove dioxins was demonstrated[8]. Although the details of the removal mechanism are not clearly understood, the removal of dioxins is presumed to occur, not by adsorption, but by oxidative decomposition of dioxins on the surface of catalyst; i.e., the breakdown of the dioxins skeleton caused by chlorine removal on the surface of catalyst.

Fig. 7 shows the relation between the space velocity (SV) and the dioxins removal efficiency across the de-NOx catalyst bed at 230 °C. As with the de-NOx reaction, a reduced SV or an increased contact time results in high removal efficiency. Thus, about 70% of the dioxins removal efficiency is expected under operating conditions that provide normal de-NOx efficiency. Therefore, depending on the NOx limit, the catalytic de-NOx method can satisfy the new standard level of 0.1 ng-TEQ/N m^3 by using a bag filter at low temperature without the injection of activated carbon. Since the operating temperature for de-NOx is normally 200 °C or above in view of the adherence of ammonium bisulfate that is produced from the reaction of SOx with ammonia, a process conducted under low

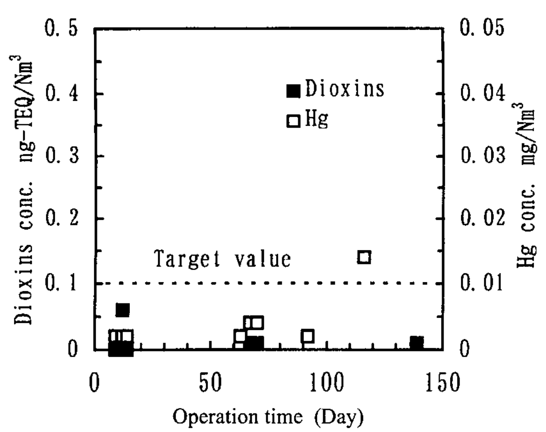

Fig. 6 Change of dioxins and Hg concentrations in outlet gas with operation time

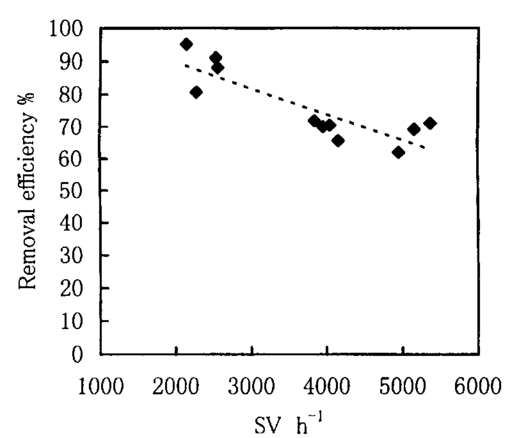

Fig. 7 Space velocity vs. removal efficiency of dioxins by de-NOx catalyst

temperature dust collection must reheat the flue gas to 200 °C or above, while a process conducted with dust collection above 200 °C allows the flue gas to pass through the catalyst bed without reheating.

Both the de-NOx reaction by supplied ammonia and the decomposition reaction of dioxins compete with each other on the catalyst surface. Accordingly, a smaller charging rate of ammonia should result in a higher dioxins decomposition efficiency. As a result, when high de-NOx efficiency is not required, the level of decomposition of dioxins that satisfy the standard level can be achieved by charging ammonia at a very slight rate without maintaining the temperature higher than 200 °C.

3. Flow of the system to reduce emissions of dioxins

By combining some of the unit operations discussed above, NKK provided several types of system that meet the respective required standard levels, as shown in **Fig. 8**.

When full combustion control is performed and the concentration at the bag filter inlet can be reduced to 2 ng-TEQ/N m³ or less, the dioxins concentration can be decreased to 0.5 ng-TEQ/N m³ or less by reducing the bag filter temperature to 160 °C. In addition, powdered activated carbon injection can be used to consistently assure a concentration level of 0.1 ng-TEQ/N m³ or less. When there is also a requirement for the NOx level to be 50 ppm or less, the use of a catalytic de-NOx unit is combined with a low temperature bag filter operation without activated carbon injection. When a dioxins concentration of 0.05 ng-TEQ/Nm³ or less is required, an adsorption tower packed with activated carbon is installed, although the large apparatus requires more space.

4. Conclusion

Effective methods to reduce the concentration of dioxins in the flue gas of municipal solid waste incinerators include the operation of a bag filter at low temperature with a high pressure differential across the filter; the injection of powdered activated carbon before the bag filter inlet; adsorption by an adsorption tower packed with activated carbon; and decomposition using a de-NOx catalyst.

By combining these methods, NKK has established customized systems in response to each required level of emission. These systems attain the target level of the new guideline of the Ministry of Health and Welfare of 0.1 ng-TEQ/Nm³ by setting the operating temperature of the bag filter at about 160 °C, by maintaining the pressure differential across the bag filter at a high level, by injecting powdered activated carbon at

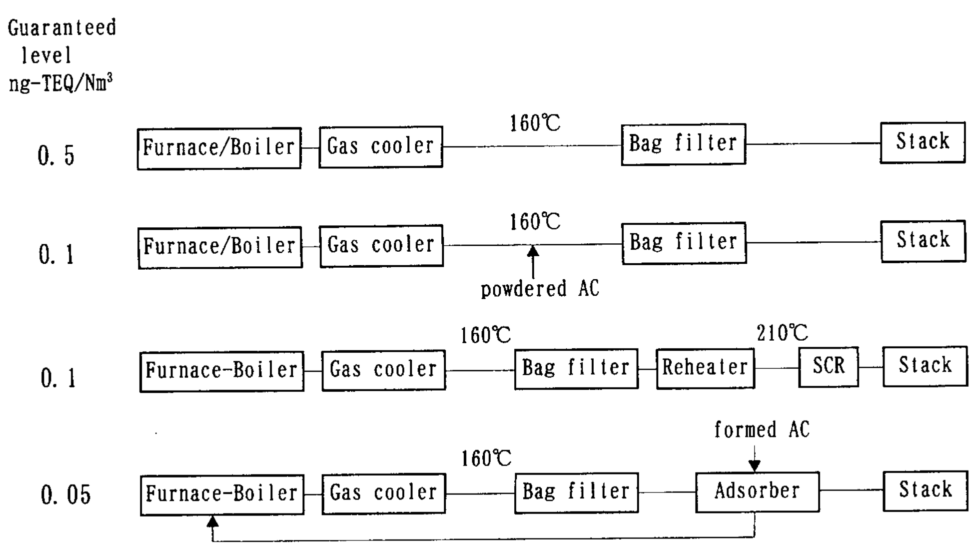

Fig. 8 NKK's standard flue-gas treatment systems for dioxin removal

the bag filter inlet, or by installing an adsorption tower packed with activated carbon. When a de-NOx catalyst is used, the target level required by the new guideline is attained by maintaining the temperature of the bag filter at 160 °C without activated carbon injection.

NKK Corporation will continue research and development to establish further accurate and reliable technology for removing dioxins. Finally, we would like to express our appreciation to the staff of local self-governing bodies relating to the project for their assistance and cooperation.

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Influence of Calcium Compound Fed to Furnace on Emissions from Fluidized Bed Incinerator

Toshihiko Iwasaki*, Takashi Noto*,
Satoshi Matsui*, Takashi Yokoyama**
and Yasuo Suzuki**

Combustion experiments using plastic pellets with a calcium compound were carried out in a bench scale fluidized bed combustor to investigate the effect of calcium as a inhibitor of PCDDs and PCDFs formation. The emission levels of PCDDs and PCDFs were measured at three points after the combustor outlet. The concentration of PCDDs and PCDFs were reduced by feeding the calcium compound into the combustor. Therefore, calcium compounds can play an important role to inhibit the formation of PCDDs and PCDFs in municipal solid waste incineration plants.

1. Introduction

The flue gas emitted from waste incinerators contains toxic materials such as HCl and dioxins (PCDDs and PCDFs). The emission of dioxins has become a serious issue in recent years. Various studies have been done on suppressing the emission of dioxins from waste incinerators. Of these, improvements that promote the complete combustion of waste was identified as an efficient means to suppress the generation of dioxins inside of the incinerators. However, the amount of dioxins are known to increase through formation between the outlet of the incinerator and the dust collector. Accordingly, for further reduction of dioxin emissions, the formation of dioxins must be suppressed at and after the incinerator outlet, in addition to the establishment of complete combustion within the incinerator[1].

Since fluidized bed incinerators can treat a wide variety of refuse, they have been used not only for incinerating combustible waste, but also for incinerating incombustible waste (i.e. waste plastics, sludge and others) and industrial waste. Recently, fluidized bed incinerators have been identified for the incineration of refuse derived fuel (RDF).

A series of incineration experiments was conducted using a bench-scale fluidized bed combustor to study the effect of limestone additions. A favorable result was found for suppressing dioxin generation, particularly in the flue duct section. This paper describes the findings on dioxin suppression and also describes the result of validation experiments using a commercial fluidized bed municipal solid waste incineration plant.

2. Combustion experiment using bench-scale apparatus

2.1 Experimental apparatus and method

Fig. 1 shows a schematic diagram of the bench-scale fluidized bed combustor (FBC) used in the combustion experiment. The fluidized bed had a refrac-

* Senior Research Engineer, Environmental Plant System Lab, Engineering Research Center
** Manager, Environmental Plant Engineering and Design Dept.

tory structure with an inside diameter of 150 mm and a height of 850 mm. The freeboard above the fluidized bed had an inside diameter of 200 mm and a height of 5300 mm. An external heater maintained the freeboard at a specific temperature. Silica sand with a mean grain size of 0.53 mm was used as the bed material. The samples were pellets of polyethylene (PE) and polyvinylchloride (PVC). Feeding limestone into the furnace was simulated with PE pellets containing $CaCO_3$ (PE(Ca)). These pellets were about 3 mm in diameter and had the composition shown in **Table 1**.

The experimental runs were performed by fully mixing these pellets in advance, and then feeding them onto the top of the fluidized bed at a constant rate using a table feeder. The mixing ratio of the pellets was set to 2 wt.% of PVC, and the addition of PE(Ca) was adjusted to specified levels of the Ca/Cl molar ratio (See **Table 2**).

The measurement of dioxin concentrations in flue gas was carried out at three sampling points, each having a different gas temperature. The sampling points shown as symbols A, B, and C in **Fig. 1** had approximate temperatures of 800°C, 280°C, and 110°C, respectively. Measurement of the HCl concentration of the flue gas was conducted in the freeboard at a height of 3000 mm above the distributor. In addition, the HCl-removal reaction within the incinerator was also studied. For monitoring the operating state, O_2 and CO concentrations were continuously determined in the flue gas duct.

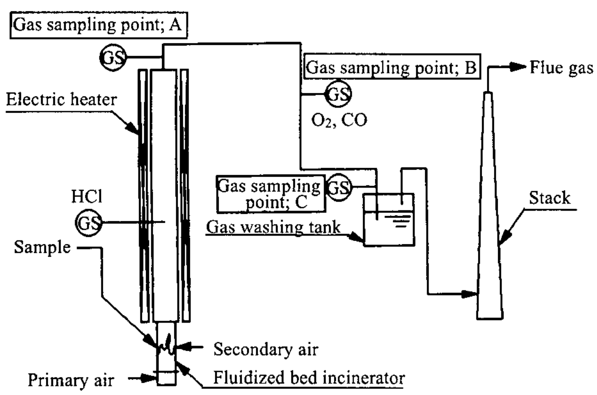

Fig.1 Schematic diagram of FBC experimental apparatus

The experimental conditions were as follows.

O_2 concentration in the flue gas duct: 8%
Freeboard temperature: 800 to 850°C
Bed temperature: 790°C

2.2 Experimental result

Throughout the bench-scale experimental runs, the CO concentration in the flue gas was kept to 1 ppm or less, and the combustion state was optimum. **Figs. 2** through **5** show the analysis of dioxins at each sampling point. **Fig. 2** and **Fig. 4** show the concentration of dioxins (PCDDs/PCDFs) without the addition of $CaCO_3$, while **Fig. 3** and **Fig. 5** show the dioxin concentrations with $CaCO_3$ at a Ca/Cl molar ratio of 2. In both cases, the concentration of dioxins increased at and after the incinerator exit (ranging from A to B). Thus, the formation of dioxins probably occurred in the temperature range of A to B. When $CaCO_3$ was fed into the combustor, the total quantity of dioxins (PCDDs and PCDFs) was less than that for the case without $CaCO_3$, even though the formation of dioxins did occur. Thus, the effect of $CaCO_3$ on suppressing the generation of dioxins was identified. **Table 2** shows the analytical results of dioxins expressed as toxic equivalents (International TEQ) and demonstrates that an increase in the Ca/Cl molar ratio decreases the toxic equivalents (I-TEQ).

Table 1 Properties of plastics

	PE	PVC	PE(Ca)
Ash	0.02	0.06	17.03
Ca	–	–	11.10
Combustibles	99.98	99.94	82.97
C	78.84	42.82	61.76
H	13.02	5.55	9.69
N	0.03	0.03	0.03
S	0.04	0.04	0.07
Cl	0.07	44.54	0.05

(dry%)

Table 2 Effect of $CaCO_3$ on PCDDs/PCDFs

Ca/Cl mol ratio	point:A	point:B	point:C
0	1.89	25.97	12.13
2	0.19	11.02	5.44
4	0.05	2.48	2.64

(ng-TEQ/Nm^3)

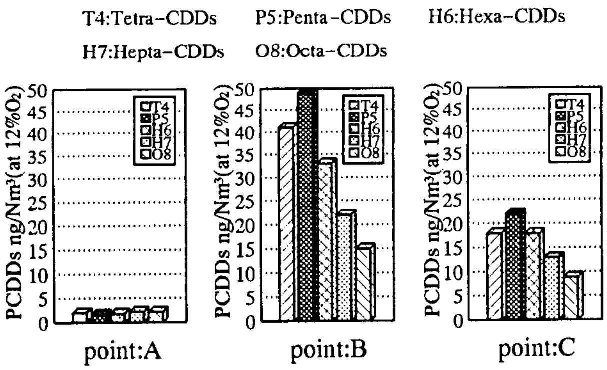

Fig.2 Concentration of PCDDs without $CaCO_3$

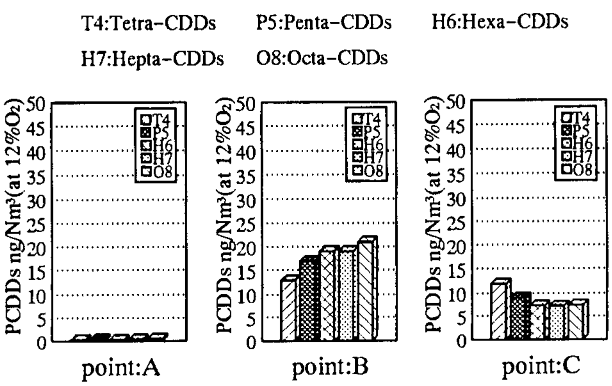

Fig.3 Concentration of PCDDs with $CaCO_3$

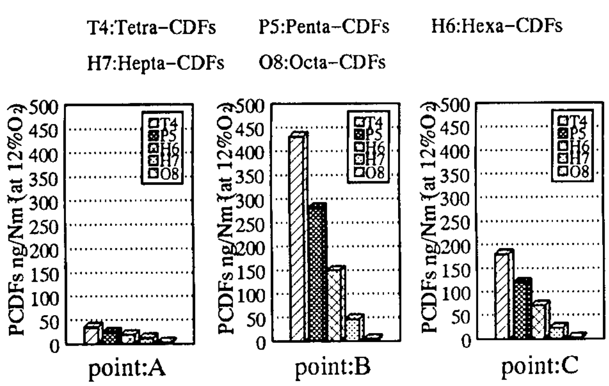

Fig.4 Concentration of PCDFs without $CaCO_3$

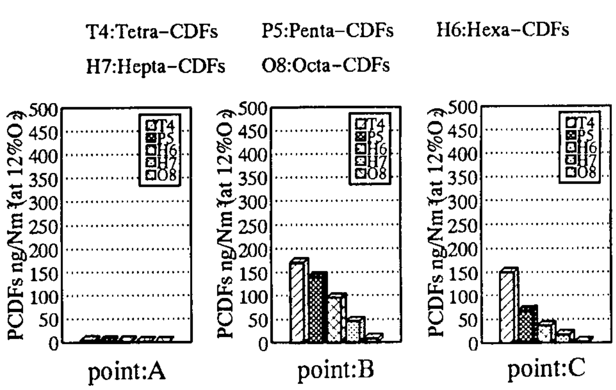

Fig.5 Concentration of PCDFs with $CaCO_3$

The relation between the charging rate of $CaCO_3$ and the HCl concentration in the freeboard was determined. The result is given in **Fig. 6**. As seen in the figure, the HCl concentration was about 200 ppm without $CaCO_3$, about 130 ppm for a Ca/Cl molar ratio of 2, and about 100 ppm for a Ca/Cl molar ratio of 4. Thus, the HCl concentration tended to decrease with the increase of Ca/Cl molar ratio. The observed HCl removal rate has a tendency that is similar to the result of Azuma et al[2]. who conducted a municipal waste incineration experiment in a stoker furnace with the injection of lime powder.

The bench-scale experiment revealed that feeding $CaCO_3$ into an combustor produces an HCl-removal reaction, and that the HCl removal rate was similar to the experience of others. Furthermore, the experiments showed that the dioxin concentrations are significantly reduced in the flue gas duct and that dioxin generation at the outlet of the furnace can be suppressed by emissions from $CaCO_3$ fed into the furnace.

3. Validation experiment in a commercial incineration plant

A commercial incineration plant was used to verify the result of the bench-scale experiments. **Table 3** outlines the commercial fluidized bed waste incineration facilities. **Fig. 7** shows a schematic diagram of the facilities.

In the validation experiment, limestone was fed into the incinerator through the sand circulation line. The HCl and dioxin concentrations were measured in

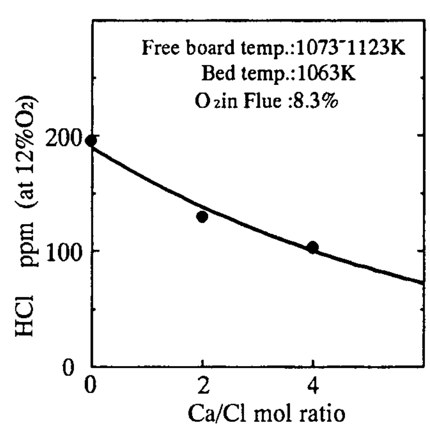

Fig.6 Relationship between Ca/Cl mole ratio and HCL

the flue gas and the results were compared to the case without limestone feeding. The feeding rate of limestone was a Ca/Cl molar ratio of 4. The HCl concentration at the outlet of the incinerator was analyzed manually, while that at the outlet of the bag filter was analyzed continuously using an automatic analyzer. Dioxins were analyzed simultaneously at four points (the incinerator outlet, the air preheater outlet, and the bag filter inlet and outlet. **Fig. 7** shows the dioxin measuring points.

Tables 4 and **5** show the flue gas analyses taken during the validation experiment. The HCl concentrations at the outlet of the incinerator and bag filter show a tendency for reduction caused by limestone feeding. This tendency is similar to that found in the bench-scale experiments. **Fig. 8** shows the result of continuous analysis of HCl concentration at the outlet of the bag filter for cases No. 1 and No. 4.

For case No. 3 given in **Table 5**, in which the flue gas analysis was conducted immediately after limestone feeding, the toxic equivalents of dioxins were similar to that without limestone. For No. 4, in which the flue gas analysis was conducted a sufficient time after limestone feeding, the toxic equivalents became low for all the analyzed points at and after the incinerator outlet. **Figs. 9** through **12** show the distribution of each dioxin, or of PCDDs and PCDFs for the cases of No. 1 and No. 4. These figures show that furnace feeding of limestone decreases the dioxin concentrations. This tendency agrees with the results of the bench-scale experiment. These experimental results demonstrated that limestone fed into the incinerator suppresses the generation of dioxins in the flue gas duct at and after the incinerator outlet. The toxic equivalents of dioxins at the bag filter outlet were less than 0.5 ng-TEQ/Nm^3, which is the target value from the "Guideline for Controlling of PCDDs/DFs in Municipal Waste Management" (ex. guideline). The guideline was prepared by the Ministry of Health and Welfare in 1990[4].

Table 3 Specification of fluidized bed incineration plant

Furnace	Fluidized bed incinerator
Capacity	30t/16h ,2 units
Flue gas cooling	Quenching by water spray
Flue gas treatment	Dry $Ca(OH)_2$ + Bag filter

Table 4 Measured result of flue gas

No.	Ca/Cl	HCl (ppm)		CO(ppm)
		Fur.out	B.F.out	B.F.out
1	0	340	60.1	26.6
2	0	270	56.2	21.4
3	4	230	37.1	11.9
4	4	230	24.9	22.8

Table 5 Effect of $CaCO_3$ on PCDDs/PCDFs

No.	Ca/Cl	Fur.out	A.P.out	B.F.in	B.F.out
1	0	5.61	5.87	6.71	1.22
2	0	1.87	6.53	5.29	1.03
3	4	1.06	6.68	6.06	1.19
4	4	0.83	2.96	2.70	0.44

(ng-TEQ/Nm^3)

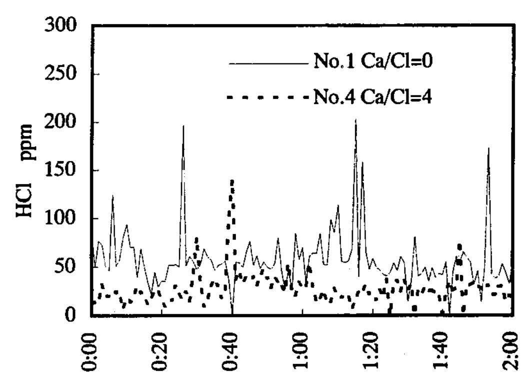

Fig.8 HCL concentration at bag filter outlet

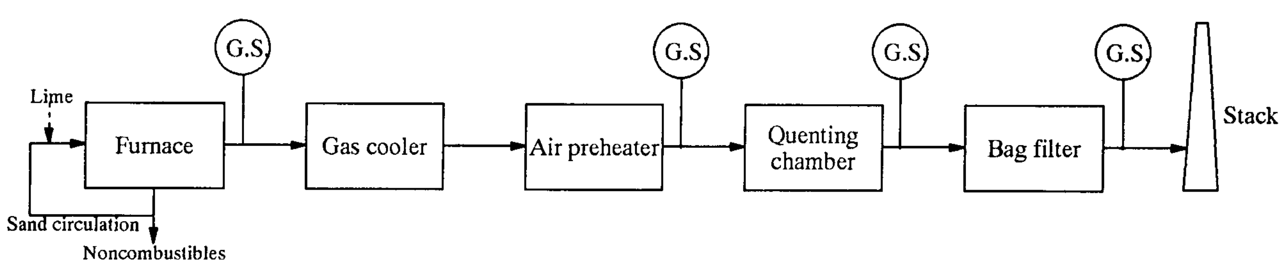

Fig.7 Schematic diagram of fluidized bed incineration plant

4. Conclusion

A series of experimental runs were conducted using a bench-scale fluidized bed combustor to study the effect of limestone feeding into the combustor on the generation of dioxins. In addition, a validation experiment was performed using a commercial incineration plant. The experiments revealed that feeding calcium compounds such as limestone into the incinerator suppresses the generation of dioxins at and after the incinerator outlet.

According to the new "Guideline for Controlling PCDDs/DFs in Municipal Waste Management," which was issued in January 1997, the limit of dioxin concentrations in flue gas is 0.1 ng-TEQ/Nm^3, which is more severe than ever for a newly constructed, continuously-operating incineration plant[5]. A combination of methods should satisfy the new requirement, i.e. the furnace feeding of calcium compounds, which was introduced in this paper, coupled with further combustion improvements and flue gas treatment, such as the injection of activated carbon.

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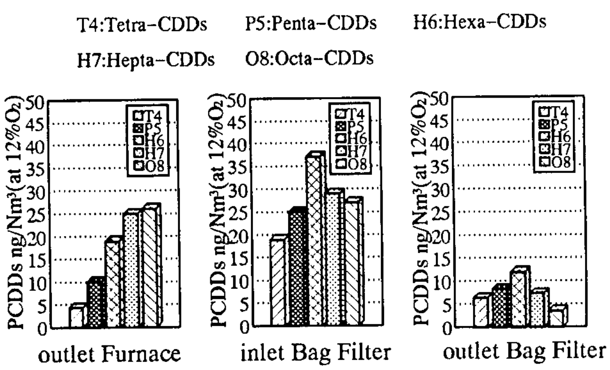

Fig.9 Concentration of PCDDs without $CaCO_3$

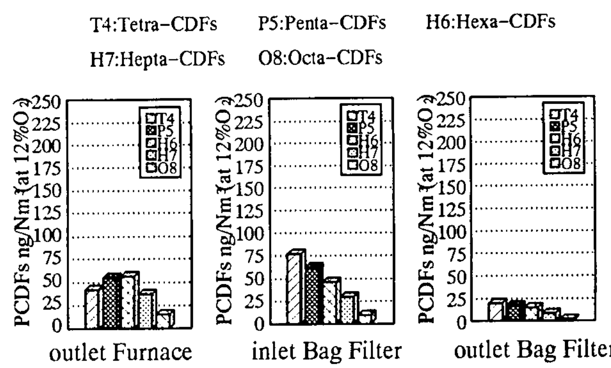

Fig.11 Concentration of PCDFs without $CaCO_3$

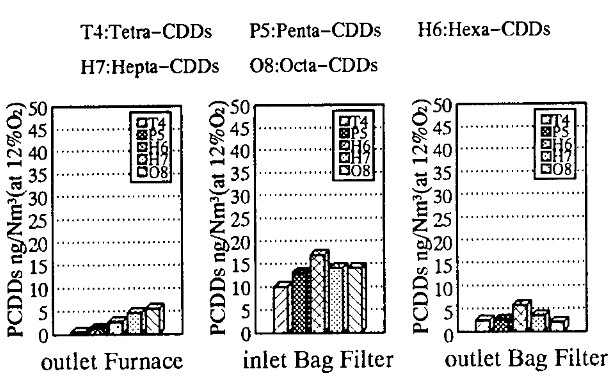

Fig.10 Concentration of PCDDs with $CaCO_3$

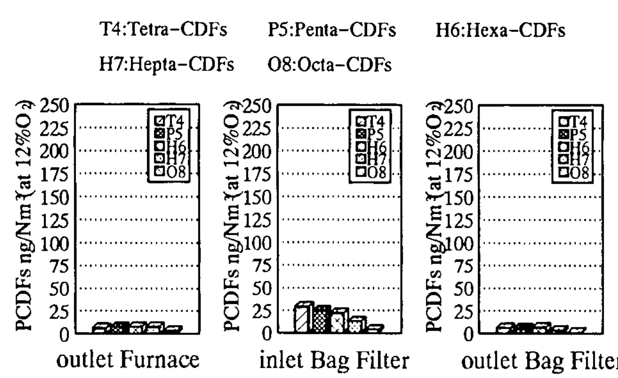

Fig.12 Concentration of PCDFs with $CaCO_3$

Control of Dioxins Emission from Stoker Type Incinerator

Yo Osada*, Satoshi Fujii**,
Minoru Suzuki***, Takehiko Aoki****
and Takashi Yokoyama*****

NKK's Two-Way Flue Gas Combustion System for a stoker type MSW incinerator can easily produce complete combustion and maintain low NOx because of the high performance combustion gas mixing system. Moreover, the addition of our automatic combustion control system (NKK hybrid ACC) permits a significant reduction of dioxin emissions (less than 1ng-TEQ/Nm^3) before the dust collector. Experiments were performed to produce stable and high temperature combustion. Results on the effect of dioxin emissions on CO concentrations, temperatures in the secondary combustion zone and water injection conditions for cooling the combustion chamber are described.

1. Introduction

Stoker incinerators comprise more than 80% of municipal waste incinerators. Stoker incinerators combust waste while it moves over the stoker (or grates), traversing in either a lateral or longitudinal furnace direction. The grates are made of heat-resistant steel with holes for air flow and form the floor of the incineration furnace. NKK's stoker furnace uses an exclusive system called the "Two-Way Flue Gas Combustion System." The furnace has an intermediate ceiling within the incineration furnace to let unburned gas from the drying zone combine with combustion gas from the post-combustion zone in the gas-mixing chamber (secondary combustion chamber) to provide mixed combustion. The system assures stable and complete combustion control, provides NOx reduction, which is supported by self-denitrification, and responds easily to load variations. In addition, the system achieved even greater combustion stability with the introduction of a hybrid ACC (automatic combustion control) system, which is an advanced combustion control system that combines control systems derived from fuzzy control and from a furnace combustion model.[1]

On the other hand, it is known that dioxins from the incineration of waste are generated during the flue gas cooling stage from slight amounts of organic compounds, or precursors, in the presence of heavy metals as a catalyst in the fly ash.[2] Accordingly, the elimination of incomplete combustion products during incineration has become a critical requirement for reducing the emission of dioxins. It is said that complete combustion needs to satisfy the "3T rule": Temperature (high temperature combustion); Time (sufficient retention time in the high temperature zone); and Turbulence (favorable agitation and mixing of combustion gas and air). According to the "Guideline for Controlling PCDDs/DFs in Municipal Waste Management ..

* Senior Research Engineer Dr., Environmental Plant System Lab, Engineering Research Center
** Senior Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
*** Senior Research Engineer Dr., Environmental Plant System Lab, Engineering Research Center
**** Environmental Plant Engineering and Design Dept.
***** Manager, Environmental Plant Engineering and Design Dept.

PCDDs/DFs Reduction Program (New Guideline)," which was recently revised and issued by the Ministry of Health and Welfare, all newly-constructed, continuous incineration furnaces need to satisfy the following combustion control conditions. The combustion temperature shall be raised by 50°C from the level specified in the old guideline (800°C minimum, 850°C or more preferred) to that of the new guideline (900°C minimum). The retention time in the furnace shall be 2 sec. or more, regardless of the type of furnace. The concentration of carbon monoxide (CO), which is an index for stable and complete combustion, shall be kept to a four-hour average of 30 ppm or less (the old guideline specified 50 ppm or less). In addition, the new guideline requests that the incinerator be operated to keep CO concentration peaks below 100 ppm to the extent possible,[3] which was not specified in the old guideline.

This paper describes the results of gas flow analysis of NKK's Two-Way Gas Combustion stoker furnace using general-purpose fluid analysis software. Studies of CO concentration variations that affect the emitted dioxins concentration, of the furnace temperature and variations, and of the relation of these to water spray conditions for reducing the furnace temperature are also reported. This data was observed in a fully-continuous operation stoker furnace with a capacity of 150 t/d. In addition, the paper describes details of the conditions for suppressing the generation of dioxins in the combustion stage.

2. Two-Way Flue Gas Combustion Stoker Furnace

NKK supplies two types of grate furnaces: the NKK hyper grate furnace with reciprocating and fixed grates, which was developed exclusively by NKK; and the fixed and movable grate furnace licensed by VØLUND. **Fig. 1** shows a schematic drawing of the NKK hyper grate furnace. The furnace is compact and assures stable combustion with a wide variety of waste qualities.[4] Both types of grate furnaces have an intermediate ceiling in the combustion chamber to separate unburned gas, which is generated in the drying zone and contains very little oxygen, from the high temperature, main combustion gas that contains a relatively large amount of oxygen. The system thus provides efficient agitation and mixing of both gases within the gas mixing chamber by forcefully directing them at each other. Inside of the gas mixing chamber, the unburned gas decomposes NOx in the main combustion gas, and air for controlling the furnace temperature is supplied for re-combustion of the gas. As a result, a uniform, high temperature atmosphere and sufficient re-combustion time are attained. This satisfies the condition for complete combustion of 850°C or more and 2 sec. or longer retention time that is required by the new guideline.

To confirm the effect, the furnace gas flow vector and the CO concentration distribution were analyzed using a general-purpose fluid analysis software.[5] The three-dimensional analysis was applied to a half domain of the actual furnace by setting a symmetrical boundary condition at the center of the furnace. To attain accurate analysis of the gas flow and combustion reactions in the gas mixing chamber, the analysis mesh in the area of the main flue gas duct and between the auxiliary flue gas duct inlet and the first boiler chamber was finer than in other areas. Various boundary conditions were established using observed values collected from measurements of the furnace combustion characteristics. **Fig. 2** shows the gas flow velocity vector distribution. **Fig. 3** shows the CO concentration distribution. The both are derived from the computation.

The analysis showed that the combustion gas enters the auxiliary flue gas duct in the drying zone and on the upstream side of the combustion zone, and enters the main flue gas duct on the downstream side of the combustion zone and the post-combustion zone. The two gas flows collide in the gas mixing chamber and mix together to form the circulation domain in the first boiler chamber. The gas flow velocity distribution becomes uniform in the transverse direction in the third boiler chamber due to the porous cell structure. On the other hand, the CO concentration is about 2.5% at the inlet of the auxiliary flue gas duct and decreases within that duct, where cooling air is injected. Thus, the gas is mixed in the circulation domain in an area ranging from the gas mixing chamber to the first boiler chamber. The CO concentration observed in the second boiler chamber in an actual furnace was about 2 ppm, which proved that the unburned gas ingredients that become dioxin precursors are nearly eliminated.

The latest design of incinerators, which are based on these analytical results, assure more efficient mixing of gases to attain complete combustion within the furnace either by adding a protrusion (nose) in the area from the post-combustion zone to the gas mixing chamber, by introducing a means to adjust the position and angle of cooling air injection, or by adding equipment to adjust the cooling air injection rate.

3. Relation between combustion control variables and dioxin concentrations

3.1 Relation between CO concentration and dioxin concentrations

The concentration of carbon monoxide was adopted as an index of incomplete waste combustion and was specified as a four hour average value of 30 ppm or less in the new guideline by Ministry of Health and Welfare. For combustion below 30 ppm of CO, however, the average CO concentration alone cannot give a clear correlation to the dioxin concentrations, so full-scale combustion control requires an operation that takes into account the fluctuation of CO concentration. Even a slight disturbance of the combustion state produces unburned ingredients such as soot that contains polycyclic aromatic compounds. These then stay in the boiler with the fly ash to produce what is called the "memory effect" that influences the concentrations for a long period of time.[6]

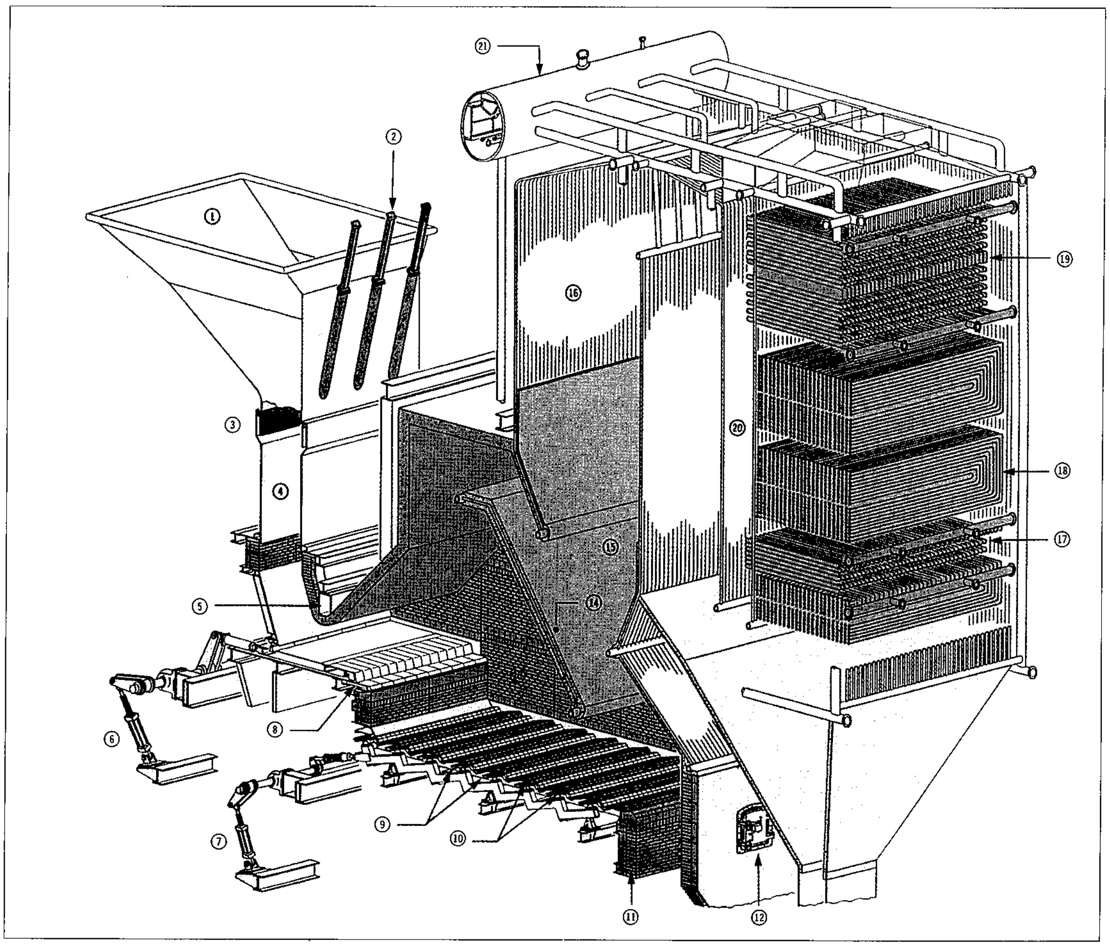

Fig.1 NKK hyper grate system

This led us to evaluate the relation between the concentration of generated dioxins by using an index of the CO concentration fluctuation or the stability of the combustion state. **Fig. 4** shows the relation between the percentage of time at a CO concentration of 30 ppm or higher while observing the dioxin concentration and the observed dioxin concentration.

When very stable combustion is established and a CO peak above 30 ppm is not detected during the dioxin observation time, the dioxin concentration at the boiler outlet is kept at or below about 1 ng-TEQ/Nm^3. If the frequency of the CO peak increases, however, it was found that a level below 1 ng-TEQ/Nm^3 is difficult to sustain.

3.2 Relation between temperature in the gas mixing chamber and dioxin concentration

The gas mixing chamber is where unburned gas coming from the drying zone collides with combustion gas from the post-combustion zone. The mixing is increased by the incoming cooling air, which ensures complete combustion of the unburned gas ingredients. Accordingly, keeping the temperature in the chamber at a high level and extending the retention time ensures the suppression of dioxin generation.

Fig. 5 shows the relation between the average temperature in the gas mixing chamber and concentra-

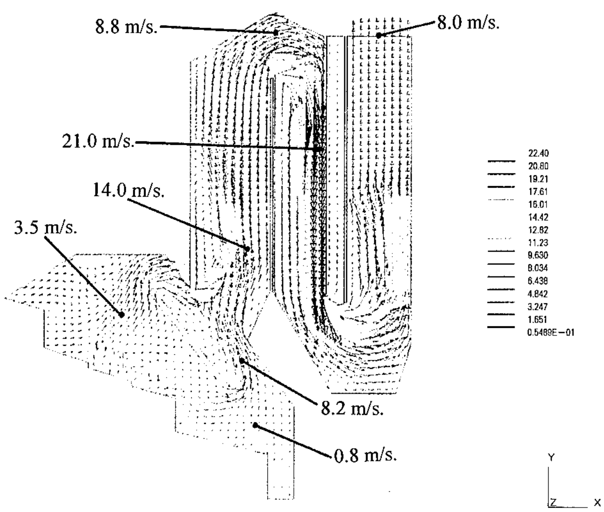

Fig.2 Predicted velocity profile

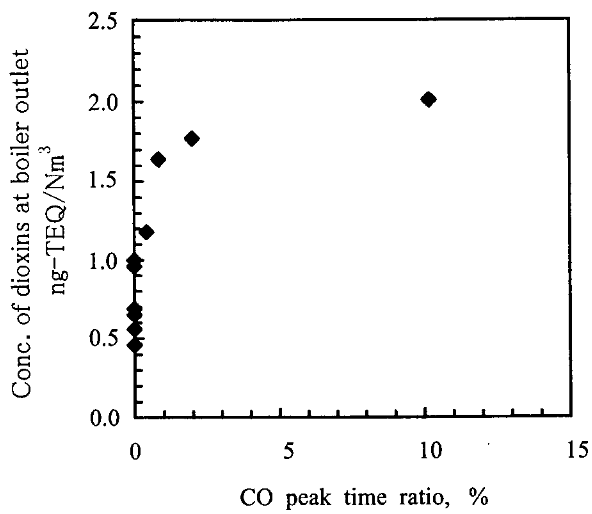

Fig.4 CO peak time ratio of over 30ppm during sampling dioxins vs. concentration of dioxins at boiler outlet

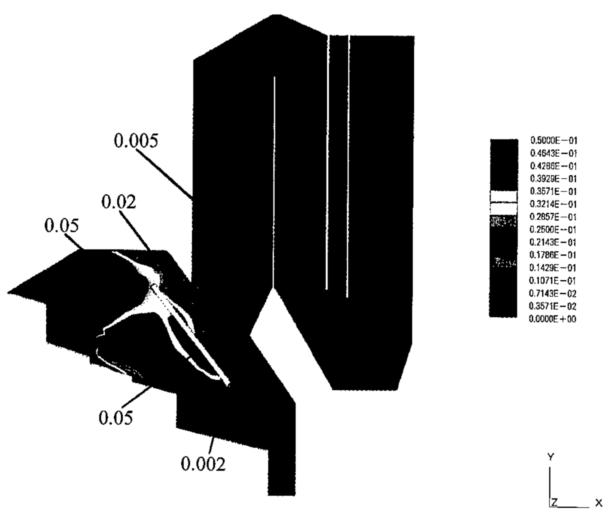

Fig.3 Predicted CO mass fraction concentration profile

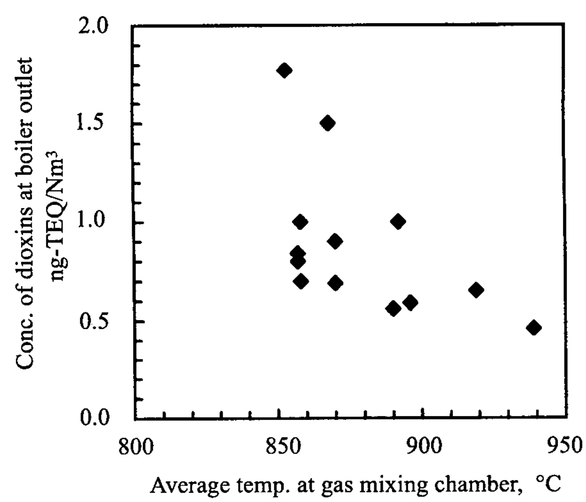

Fig.5 Average temperature at gas mixing chamber vs. concentration of dioxins at boiler outlet

tion of dioxins at the boiler outlet. **Fig. 6** shows the relation between the dioxin concentration and the minimum temperature in the gas mixing chamber that was observed while the dioxin concentration was being determined. This relation is an index of combustion stability in the gas mixing chamber. The relation revealed that increasing the average temperature in the gas mixing chamber significantly decreases the dioxin concentration, and that it is effective to maintain the temperature in the gas mixing chamber within the range of 850 to 900°C, which is the range specified in the new guideline. It was confirmed that the relation between the minimum temperature in the gas mixing chamber and the dioxin concentration has a similar tendency. From these results, it was found that high temperature combustion with a minimum temperature of 850°C in the gas mixing chamber is critical for suppressing the dioxin concentration at the boiler outlet to 1 ng-TEQ/Nm³ or less.

3.3 Relation between furnace water spray rate and dioxin concentration

When the gas mixing chamber is maintained at a high temperature, the generation of dioxins is suppressed. If, however, the temperature becomes excessively high, bad effects tend to appear, such as the adhesion of ash onto the furnace wall (generation of clinker), the increase in thermal NOx generation, and the thermal corrosion of boiler water tubes. In particular, the incineration of high calorific refuse results in an excessively high furnace temperature that is likely to induce these bad effects. As a countermeasure, the furnace atmosphere is cooled by spraying water through nozzles located in the upper part of the combustion zone. We therefore investigated the relation between the water spray condition and the concentration of emitted dioxins. **Fig. 7** shows the relation between the water spray rate and the dioxin concentration at the bag filter inlet. **Fig. 8** shows the relation between the standard deviation of the water spray rate and the dioxin concentration.

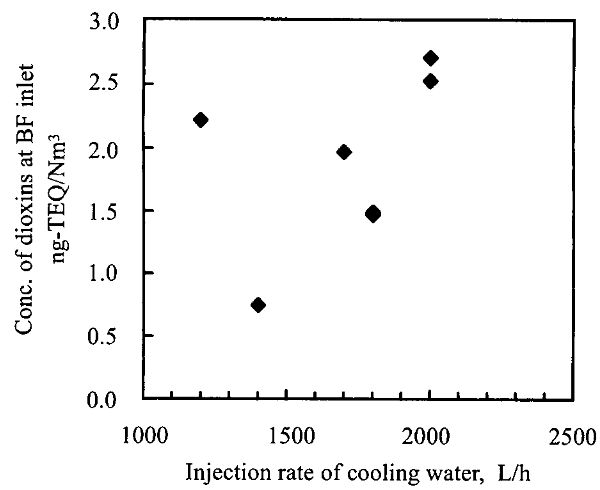

Fig.7 Injection rate of cooling water vs. concentration of dioxins at baghouse inlet

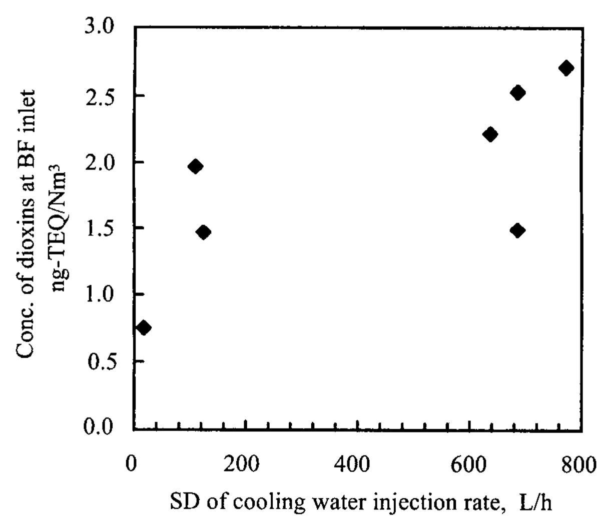

Fig.8 Standard deviation of cooling-water injection rate vs. concentration of dioxins at baghouse inlet

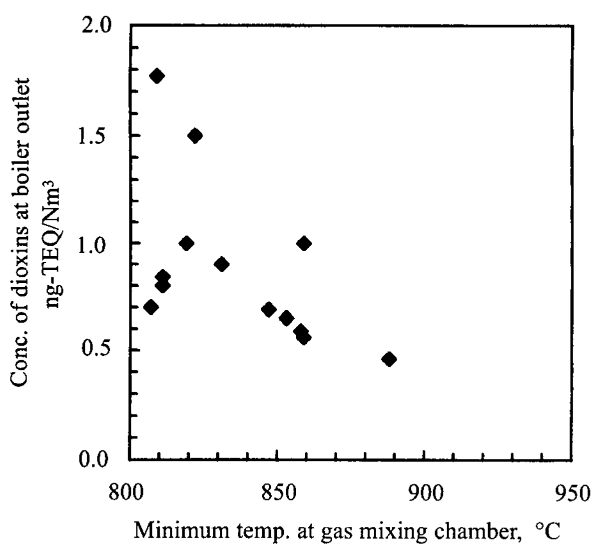

Fig.6 Minimum temperature at gas mixing chamber vs. concentration of dioxins at boiler outlet

The average water spray rate is related to the temperature in the gas mixing chamber, suggesting a positive correlation with the standard deviation, although no definite correlation was observed. The relation suggests that dioxins are likely to be generated when the water spray rate varies over a wide range so that the combustion gas is cooled by an excessive amount of water spray, even if the excessive spray is applied for a short time. The presumed reason is that direct contact of water with the flame freezes the combustion, which easily generates soot that becomes a major contributor to the generation of dioxins during the gas-cooling stage. Consequently, control of the furnace water spray rate must be responsive to the changing furnace temperature.

4. Conclusion

Observation of an actual incinerator revealed that improving the mixing performance of gases in the secondary combustion chamber and maintaining the temperature in the chamber over 850°C are critical variables for suppressing the generation of dioxins accompanying waste incineration. NKK's Two-Way Flue Gas Combustion stoker furnace has an inherent structure that can easily attain these conditions. With the introduction of a hybrid ACC, which was exclusively developed as an advanced, automatic combustion control system, the gas state at the furnace outlet can be maintained at a high temperature and stable condition, while suppressing the occurrence of a CO peak. This system suppresses the generation of dioxins to 1 ng-TEQ/Nm^3 or less at the inlet of the flue gas treatment unit.

We would like to express our appreciation to the staff of the related local governments for their support and help.

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Automatic Combustion Control System for Fluidized Bed Incinerator

Minoru Tanabe* and Hajime Akiyama**

NKK evaluated the use of heat from incineration plants to conserve energy and to decrease environmental pollution and developed a combustion control system for fluidized bed incineration plants that provides these benefits through steady combustion. Three such combustion control systems are now in practical use. The system controls fluidized bed incineration plants effectively.

1. Introduction

Incinerators may be classified into three types: stoker, kiln, and fluidized bed. Fluidized bed incinerators have been used in many fields because of their superior combustion characteristics for urban refuse, industrial waste, sludge, and plastics. NKK developed a fluidized bed incinerator to meet these demands and achieved sales success[1].

One feature of the fluidized bed incinerator is its fast rate of combustion. Although the incinerator is easy to start and stop, combustion control is difficult.

The number of plants with generating facilities such as boiler-turbines is increasing to make effective use of refuse combustion heat. In such plants, combustion stabilization is important for providing a stable steam supply and amount of power generation.

With the recent growing interest in environmental problems, refuse disposal with low pollution has become an important issue. Toxic substances in the incinerator exhaust gas contain NOx, CO, and dioxin, which are partly caused by unstable combustion. Therefore, stable combustion is essential to prevent pollution.

Because of this need to stabilize combustion, NKK developed a combustion control system for fluidized bed incinerators that was commercialized in 1996. Three systems are presently in operation at 2 sites. The combustion control system is described in this report.

2. Fluidized bed incinerator

Fig. 1 shows the fluidized bed incinerator. The crane carries refuse from the refuse pit to the refuse feeder, which injects the refuse into the incinerator. The refuse contacts the sand at a temperature of about

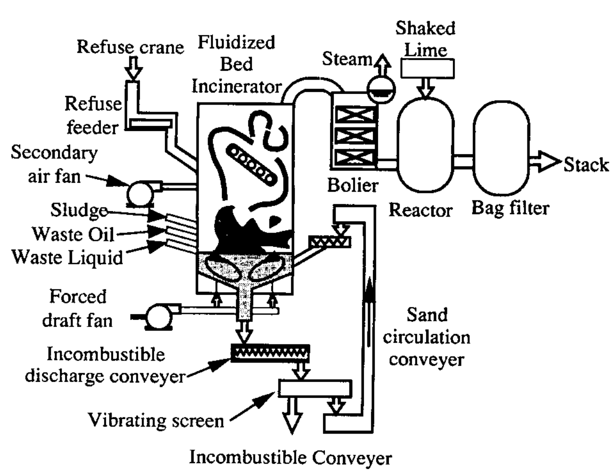

Fig. 1 Fluidized bed incineration plant

* Senior Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
** Environmental Plant Engineering and Design Dept.

600 °C and is fluidized by the primary air. It is dried, decomposed by heat, and partly burned. The combustible gas generated by the decomposition contacts secondary air and quickly burns. The heat-decomposed solid remains to burn slowly in the sand. Exhaust gas from the incinerator goes through heat recovery and exhaust gas treatment processes before entering the chimney. Incombustible material is discharged with the sand from the bottom of the furnace. The sand is returned into the furnace after classification.

The start and stop operation of the fluidized bed incinerator is easier than a stoker (fire grate) furnace. It also has the advantages of its fast combustion speed and its ability to combust a wide range of refuse, from sludge with low heating value to waste plastics with high heating value. However, combustion control is more difficult than with a stoker furnace because of its fast combustion speed. It is inherently difficult to supply refuse at a constant volume. For example, when a large volume of refuse enters the furnace at one time, it burns quickly, causing the pressure in the incinerator to rise and the generation of CO to increase due to temporary incomplete combustion. This sudden combustion is completed within several seconds after the refuse enters, so feedback control is difficult.

3. Combustion control system

3.1 Conventional combustion control

As shown in **Fig. 2**, a PID controller and sequential Combustion Support System (CSS) were conventionally used for combustion control of fluidized bed incinerators. The PID controller controls the refuse feeder speed and the secondary air volume at a fixed value. A general waste incinerator has only one refuse feeder, but industrial waste incinerators need to combust a variety of refuse in different shapes and heat values, such as solid refuse, sludge, waste liquid, and waste oil. Each type of refuse is injected into the incinerator through its corresponding feeder. Thus, each feeder must be set based on its feeding characteristics and the incineration load.

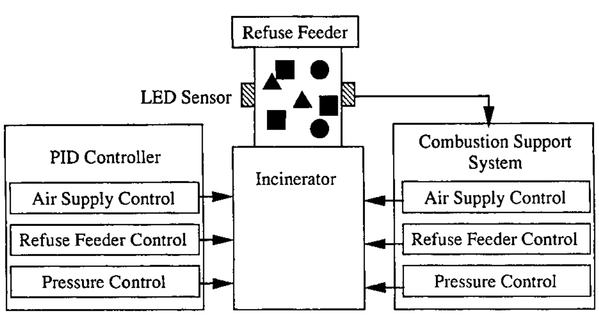

Fig. 2 Combustion support system

On the other hand, to avoid sudden pressure increases and the deterioration of exhaust gas caused by excessive refuse feeding, when the CSS detects an excess signal, it initiates a sequence of operations to increase the secondary air volume, change the primary air volume, stop the feeders, reduce pressure in the incinerator, and close the dampers under the feeders. These operations are the result of our operational knowledge of fluidized bed incinerators that we have gained through past experience. We applied an expert system to the combustion control process. The CSS avoids abnormal combustion effectively, but contributes little to improve normal combustion. Therefore, the following problems still existed in the conventional control system:

(1) Control of the refuse feed volume is not sufficient to stabilize combustion conditions if variations in the refuse heat value are large.

(2) The problem of item (1) sometimes increases because the ability to supply refuse at a constant volume differs greatly, even if the refuse feeder speed is kept constant, because it depends on the refuse properties.

An understanding of the exact combustion conditions and the development of an operational control scheme were required to solve these problems.

3.2 Fuzzy control

We adopted the fuzzy control method[2), 3)] to the development of the combustion control system. The fuzzy control system has the following advantages:

(1) Control rules can be described linguistically. As a result, we can use our knowledge of the fluidized bed incinerator and the operators' operational know-how to shorten the development period.

(2) We can address specific details of each customer's plant.

(3) We can flexibly accommodate additions and changes of control items.

Therefore, we concluded that a fuzzy system would be useful for plants with large variations in refuse properties. In particular, item (1) permits us to easily create and use control rules for evaluating combustion conditions by the combination of various measurement values. Actually, operators perform several operations that are harmonious with each other based on such judgments. This is the most significant departure from a conventional control system.

Because of the possibility of untimely control under normal control at regular intervals, we decided to apply the CSS continuously to accommodate sudden excessive refuse feeding. The CSS can increase the secondary air volume, change the primary air volume, stop the feeders, reduce pressure in the incinerator, and close the dampers under the feeders. The combustion control system sets the values and times only for these operations.

3.2.1 Membership function

The control rules and membership functions determine the performance of fuzzy control. We specified the membership functions based on the following concepts:

(1) The Number of membership functions

More precise control is possible with a larger number of membership functions (number of fuzzy divisions) for each measurement or operation value. However, this reduces the ability to maintain the system because of the increased number of parameters to be controlled. Based on our previous experience with the operation of fluidized bed incinerators, we decided to assign three membership functions per measurement value for the combustion control system.

(2) Combination of membership functions

More precise control is possible with the use of a large number of membership functions for the requirements part of a control rule. However, resulting complexity reduces maintainability. A method to avoid this complication is to build a hierarchy of control rules, but it is not always possible to build a hierarchy depending on the control items. Therefore, we decided to use simply-described control rules for the combustion control system and increased the number of control rules to assure performance.

(3) Shape of membership function

Triangular-, trapezoidal-, or bell-shape membership functions are generally used, but we could not find substantial differences between them. We used a trapezoid-shaped membership function for the combustion control system because we could set tolerances on the set values. This allows the operator to "see what happens" without changing the present conditions if the plant condition is within tolerance and corresponds to the dead zone. **Fig. 3** shows the shapes of the membership functions used in the combustion control system.

3.2.2 Control rule

We developed control rules for the combustion control system based on operational knowledge acquired by interviews with our design engineers and operators. The rules are roughly divided into the following categories:

(1) Rules to control the speed of each refuse feeder to ensure the required amount for each kind of refuse

(2) Rules to control the speed of each refuse feeder to maintain the appropriate temperature (especially the temperature at the furnace exit)

(3) Rules to control the speed of each refuse feeder to absorb variations in the amount of steam generation

(4) Rules to control pressure in the incinerator in response to the feed volume for the various kinds of refuse

(5) Rules to control the secondary air volume at short intervals in response to the feed volume for the various kinds of refuse

(6) Rules to control the secondary air volume at long intervals in response to the concentration of O_2 in the exhaust gas

(7) Rules to determine CSS set values depending on refuse quality.

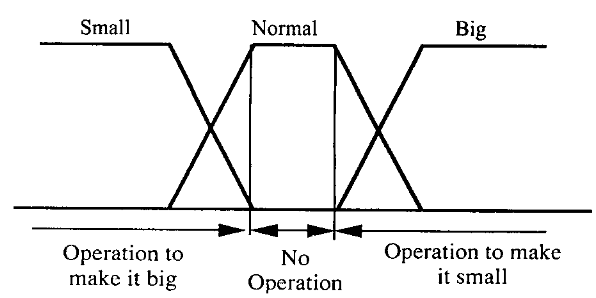

Fig .3 Membership function

3.3 System operation

Fig. 4 shows the actual system configuration. The functions of each subsystem will be explained based on signal flow.

First process signals from various kinds of sensors installed in the plant enter the DCS (Distributed Control System) as a single unit.

The DCS provides low-level control, such as settings for the upper and lower limits of the incinerator control signals and the number of burners and nozzles, and PID parameters for the dampers and control valves. It also monitors the plant. In addition, it controls other facilities such as the attemperator tower, gas purifier, and bag filter.

Process signals that are necessary for incinerator control are digitized and sent to the PLC (Programmable Logic Controller) from the DCS. In the PLC, the CSS increases the secondary air volume, changes the primary air volume, stops the feeders, reduces pressure in the incinerator, and closes the dampers under the feeders to deal with sudden excessive refuse feed. The Automatic Combustion Control System (ACC) defines settings for the CSS based on fuzzy inference. The PLC also maintains the data necessary for the ACC's fuzzy inference.

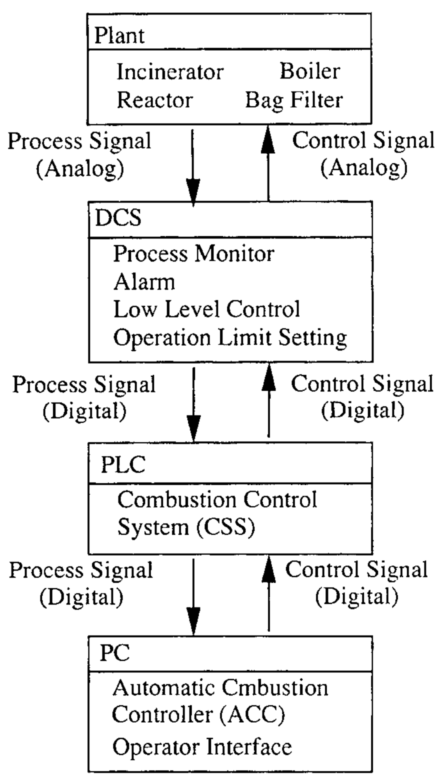

Fig. 4 System configuration

The ACC is software on a personal computer and is composed of the modules shown in **Fig. 5**. Actually, it is the combination of a general-purpose fuzzy inference engine, control rule base, signal input/output area (for process signal input and control signal output), a parameter area where the operator enters settings, a signal transmission input/output module between the input/output signal area and the plant (normally a communication program on the DCS), an input/output definition file for allocating signals to the input/output signal area, a rule definition file describing the control logic, and the user interface module for the operators.

Of these, the general-purpose fuzzy inference engine, the control rule base, the input/output signal area for the process signal input and the control signal output, and the parameter area where operators enter settings are commonly used modules that are independent of the requirements of the individual customer's plant.

On the other hand, the input/output module, input/output definition file, rule definition file, and user interface modules depend on the requirements of the customer's plant.

This modular configuration allows us to apply nearly the same configuration to another customer's plant by changing only part of the rule definition. It also simplifies the customization of interfaces. **Figs 6** and **7** show examples of user interfaces.

The ACC reads the process data shown in the input signal column of Table 1 from the PLC at regular intervals. It then performs preliminary processing, such as data smoothing and differentiation, uses the control rule database as a reference to make fuzzy inferences, and defines the operating values shown in the output

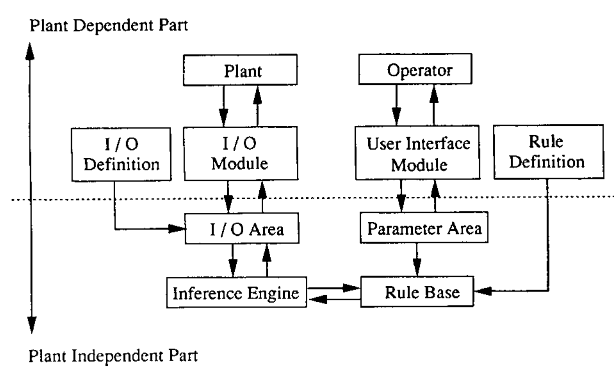

Fig. 5 Automatic combustion control system

signal column of **Table 1**. **Fig. 8** illustrates this process. The defined values are written into the PLC.

The PLC sends the operation values written by the ACC to the DCS and changes the CSS settings.

The DCS receives data from the ACC through the PLC and uses the data to control the system and to determine PID control settings for the actual output control signals for each operational interface.

4. Results of actual system operation

The combustion control system is now in use for the fluidized bed industrial waste incinerator at the Toyota Motors Corporation complex industrial waste treatment facility. Installation of this facility was completed at the end of July 1997. **Table 2** shows specifications for the incinerator.

Fig. 9 shows the temperature and concentrations of the CO and NOx in the exhaust gas of the incinerator after installing the developed combustion control system. The temperature at the furnace exit is stabilized at about 1000°C, which is higher than the 850°C temperature necessary for complete combustion. The system meets the guaranteed value of 50ppm CO for pollution control. The value for NOx is about 60ppm, which is well below the guaranteed value of 95ppm for pollution control of the plant. The system uses 103 fuzzy rules for controlling the supply volumes of the various kinds of refuse, 24 for the secondary air volume, and 12 for the CSS settings.

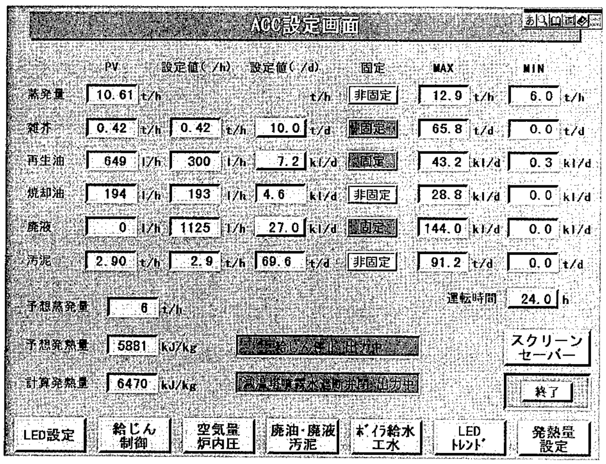

Fig. 6 ACC outlook

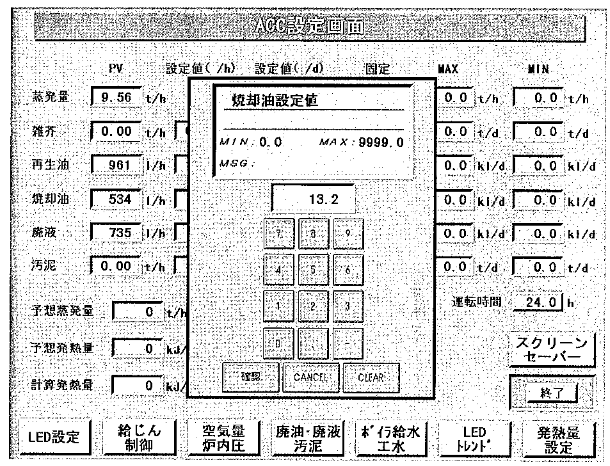

Fig. 7 ACC operator interface

Table 1 I/O signals

Input Signal	Output Signal
Air Flowrate (Primary, Secondary)	Secondary Air Flowrate
Pressure in Incinerator	Refuse Feeder Speed
Temperature (Fluidized Bed, Freeboard, Top of Incinerator)	Refuse Supply
Refuse Feeder Speed	Waste Oil Supply (Freeboard, Fluidized Bed)
Refuse Supply	Waste Liquid Supply (Freeboard, Fluidized Bed)
Sludge Supply	Sludge Supply
Waste Oil Supply (Freeboard, Fluidized Bed)	Boiler Water Supply
Waste Liquid Supply (Freeboard, Fluidized Bed)	Cooling Water Supply (Freeboard, Fluidized Bed)
Cooilng Water (Freeboard, Fluidized Bed)	Boader Value (To Stop Refuse Feeder , for CSS)
LED Count	Control Time (To Stop Refise Feeder, for CSS)
Mean Calolific Value	Boader Value (To Control Primary Air , for CSS)
Steam Generation	Control Time (Primary Air Air Flowrate, for CSS)
Boiler Water Supply	Boader Value (To Control Secondary Air , for CSS)
Boiler Level	Control Value (Secondary Air Flowrate, for CSS)
Exhaust Gas Flowrate	Control Time (Secondary Air Flowrate, for CSS)
Exhaust Gas Component (O_2, CO, NOx, SOx, HCl)	Boader Value (To Control Pressure, for CSS)
	Boader Value (To Stop Waste Oil, for CSS)
	Boader Value (To Stop Waste Liquid, for CSS)

5. Conclusion

NKK developed a combustion control system to stabilize combustion of a fluidized bed incinerator. The results of the actual operation of the developed combustion control system met the performance requirements for a fluidized bed incinerator that can tolerate large variations in combustion. We will continue our research and development to make the combustion control system more effective.

Finally, we would like to acknowledge with gratitude all the staff of Toyota Motors Corporation who greatly helped us in the collection of the actual operational data.

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Table 2 Plant specifications

Plant capacity	159.6 t/d (4.98×10^{10} kcal/d)
Gas Cooling System	Boiler (18.3 t/h, 23kg/cm^2)
Environmental Quality Stanard	HCl >80ppm (12%O_2)
	SOx >175ppm
	NOx >95ppm (12%O_2)
	CO >50ppm (12%O_2)
	Dust >30mg/Nm^3

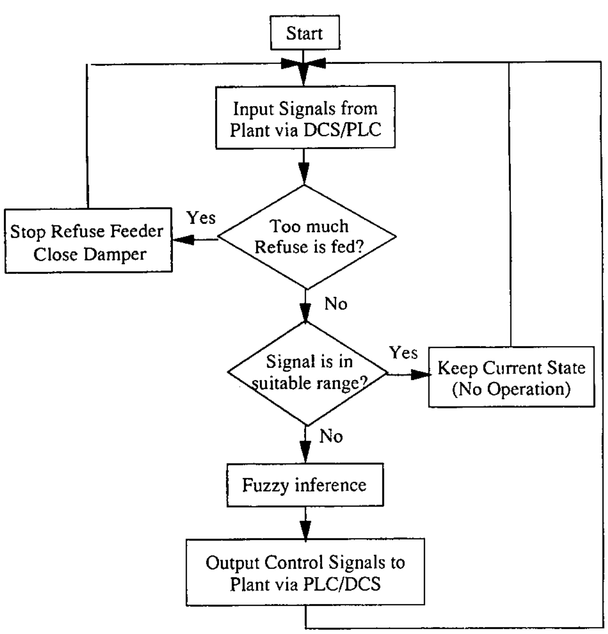

Fig. 8 Flow chart of fuzzy combustion control

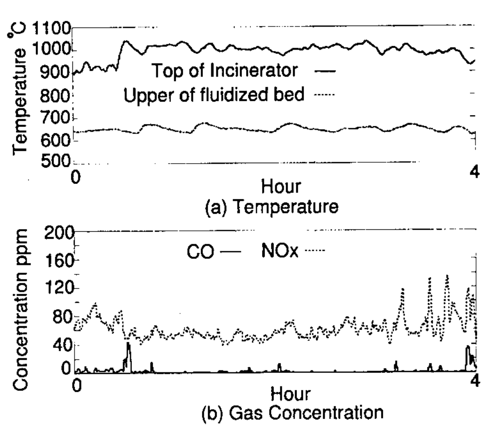

Fig. 9 Control result with ACC

Hybrid Combustion Control System for Refuse Incineration Plant

Satoshi Fujii*, Manabu Kuroda**,
Yuichi Nogami***, Hajime Ase****,
Eiichi Shibuya***** and Takashi Yokoyama*****

NKK developed a new, automatic combustion control system for a municipal refuse incinerator with a boiler-turbine that increases the stability of steam flow from the boiler, while simultaneously reducing CO and NOx concentrations in the exhaust gas. This control system consists of a simulation model-based controller, which stabilizes the steam flow rate and inner temperature, and a fuzzy based controller, which adjusts the secondary air to reduce CO and NOx concentrations. This control system was installed in a working incinerator and has provided good control performance.

1. Introduction

Refuse incinerators have an important role in disposing much of the refuse from our society. In recent years, general interest has grown increasingly in the reduction of toxic substances and the recovery of the large amount of heat energy produced by refuse incineration.

In addition to the exhaust gas regulations for NOx, HCl, and SOx, new guidelines for dioxins were made public in January, 1997. Thus, the pollution control requirements for refuse incinerators have been getting tougher every year. However, there are conflicts between methods for suppressing the generation of CO and NOx, and both affect the generation of dioxins. Therefore, it is not easy to suppress both CO and NOx at the same time. On the other hand, the number of plants with generating facilities such as boiler-turbines is increasing to make effective use of refuse incineration heat. In such plants, highly stabilized steam generation is another important subject.

NKK's line of stoker incinerators include the conventional NKK-VΦLUND type and the Hyper-Grate type, which we originally designed in response to the recently changing situation of refuse disposal. Since these types of incinerators are unique in having a two-way gas flow system with an intermediate ceiling, they inherently have excellent combustion capabilities and can easily control NOx emissions by using two stage combustion. They are also equipped with an automatic combustion control system for stable combustion control[1), 2)]. The exhaust gas levels are well below all regulations. However, more precise combustion control has become necessary to meet the social requirements de-

* Senior Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
** Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
*** Manager, Electrical Control Engineering Dept.
**** Manager, Dr. Electrical Control Engineering Dept.
***** Manager, Environmental Plant Engineering and Design Dept.

scribed above.

NKK developed and commercialized a hybrid, automatic combustion control system (Hybrid ACC) to simultaneously reduce both CO and NOx in the exhaust gas and stabilize the amount of steam generated. This report describes the Hybrid ACC control method and the results of actual combustion control.

2. General description of refuse incineration plant

Fig. 1 shows a flow diagram of the hyper grate incinerator. Refuse at the bottom of the refuse hopper chute is carried onto the grate, which is located at the same level, by the reciprocating motion of the refuse feeder. The refuse is stirred while it travels on the grate. The refuse on the grate is dried and burned by combustion air from below the grate. Finally, the refuse is sent to the after-burning zone, where it is burned completely into ash and then discharged from the furnace.

The flow of combustion exhaust gas is in two paths: the main flue and the bypass flue. Gas is mixed and unburned gases are re-combusted in the gas mixing chamber. The heat of the exhaust gas after mixing and re-combusting is recovered by the boiler. The exhaust gas goes through the exhaust gas treatment system and out the stack. The steam generated in the boiler is sent to the turbine for power generation.

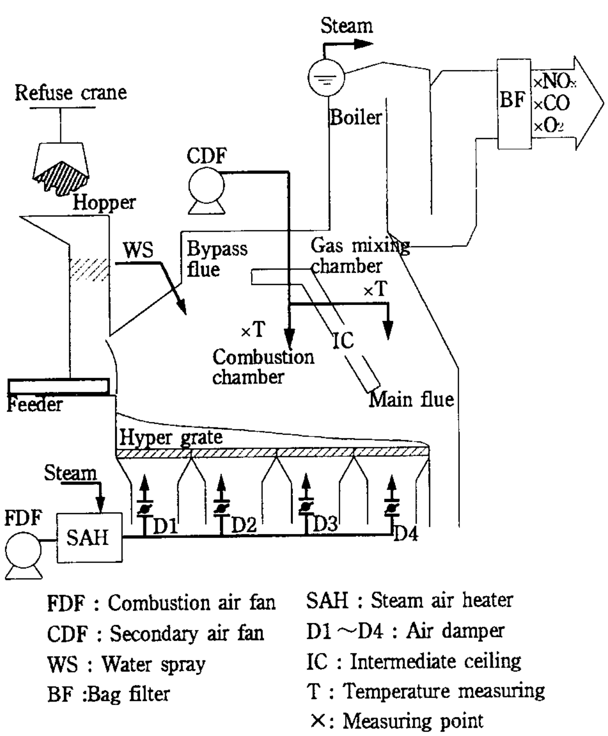

Fig. 1 Refuse incineration plant

3. Factors causing CO and NOx generation

3.1 Characteristics of CO and NOx generation

The relationship between the actual operating conditions of the incinerator and the generation of CO and NOx must be quantitatively measured in order to design a control system for reducing the concentrations of CO and NOx.

After systematic data measurements and analyses on a number of actual incinerators, we found that CO suddenly increases in the following two cases (**See Fig. 2**).

Case 1: Oxygen (O_2) depletion due to intensified combustion causes CO generation.

Case 2: CO is generated under the abundant supply of O_2 when O_2 cannot re-combust the CO due to low temperatures.

3.2 Relations among CO, NOx, and temperature

The results of analysis of the data from actual incinerators are shown in **Fig. 3** as static relations between CO, NOx, and gas mixing chamber temperature against the secondary air volume. Cases 1 and 2 de-

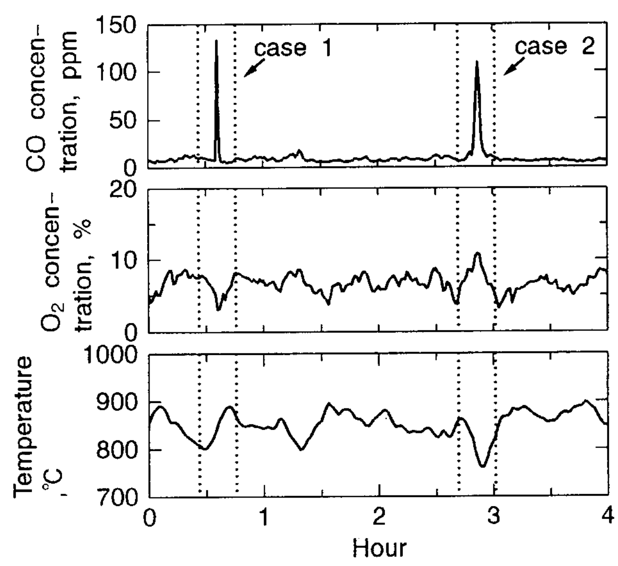

Fig. 2 Relation among CO, O_2 and temperature

scribed above correspond to Zones I and III in the figure, respectively. Both CO and NOx are maintained at low concentration levels for the combustion conditions in Zone II of **Fig. 3**.

4. Introduction of hybrid control

Our analyses indicated that effective control of combustion is possible if conditions are always maintained within Zone II of **Fig. 3**. First we had to stabilize long-term combustion. This can be done by stabilizing the volume of refuse supplied based on the amount of steam generation specified, by keeping the refuse volume remaining in the furnace at a constant level, and by appropriate control of the combustion air volume. On the other hand, abrupt changes in combustion due to variations in refuse quality occur frequently in the incinerator. These phenomena cannot be modeled and controlled with a model-based control system, so we used a fuzzy control system to suppress such short-term variations. Thus, we can maintain stable, long-term and short-term combustion in the incinerator by combining these two control systems with their different characteristics and purposes(**Fig.4**).

5. Control system for long-term combustion stabilization

5. 1 Modeling of combustion process

The control system for stabilizing long-term combustion was designed based on analyses of the dynamic responses of each operation in the incinerator and on the effects of changes over time of the refuse volume and composition supplied to the incinerator. Prior to these analyses, an incinerator combustion model was developed to confirm the operation and effectiveness of the control system. The basic assumptions in the modeling are as follows.

(1) Refuse on the grate is divided into blocks based on the position of the combustion air wind boxes (1 step for drying, 2 steps for combustion, 1 step for after-burning).

(2) Gas flues are divided into blocks for the combustion chamber, the bypass flue, the main flue, and the gas mixing chamber.

(3) Each block model is assumed to be a complete mixing model based on heat and material balances.

(4) Refuse is assumed to consist of water, ash, and combustible material made of C, H, and O.

(5) Reactions in the refuse layer and the gas flues are shown in the following equations (1)~(5).

$$C + O_2 / 2 = CO + Q_1 \quad ......(1)$$

$$C + O_2 = CO_2 + Q_2 \quad ......(2)$$

$$CO + O_2 / 2 = CO_2 + Q_3 \quad ......(3)$$

$$CH_4 + 2O_2 = CO_2 + 2H_2O + Q_4 \quad ....(4)$$

$$H_2O(1) = H_2O(g) + Q_5 \quad ......(5)$$

where,

Q_i; i=1~5: heat of reaction or evaporation

Fig. 5 illustrates the general structure of the model based on these assumptions.

In **Fig. 5**, the blocks of the refuse on the grate and the flues are constructed on the basis of material and heat balances. Examples of material and heat balances for the refuse are shown in the following.

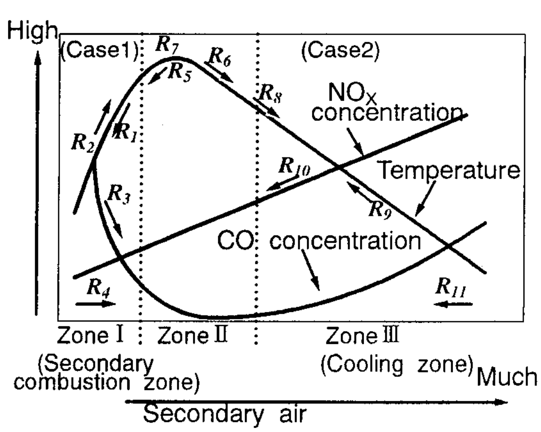

Fig. 3 Relation among CO, NOx and temperature

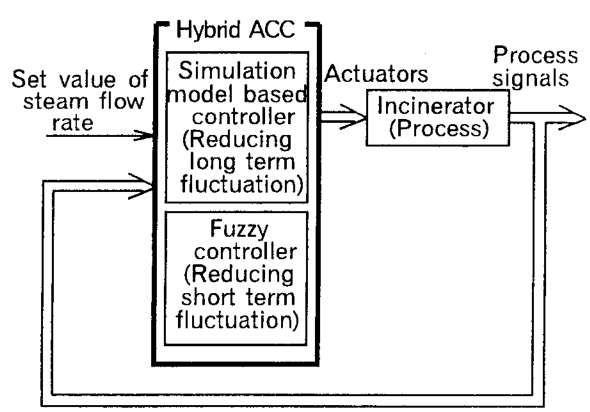

Fig. 4 Schematic diagram of Hybrid ACC

$$dW_{ij}/dt = V_{i-1}W_{i-1j} - V_i W_{ij} + R_{ij} \quad \text{......(6)}$$

$$d(\sum_j C_j W_{ij} T_i)/dt = V_{i-1}\sum_j C_j W_{i-1j} T_{i-1} - V_i \sum_j C_j W_{ij} T_i + Q_{ri} + Q_{gi} + Q_{fi} + \sum_j Q_j R_{ij} \quad \text{......(7)}$$

where,

i : a numerical subscript for a block number

j : a numerical subscript for a component

W_{ij} : weight of j component

V_i: moving speed of refuse

R_{ij} : reaction or vaporization rate of j component

C_j : specific heat of j component Ti: refuse temperature

Q_{ri} : heat transfer from combustion air to refuse

Q_{gi} : heat transfer from combustion gas to refuse

Q_{fi} : heat transfer from flame on refuse layer surface to refuse

5.2 Simulation

To verify that the model properly simulates incinerator combustion, we compared its response to that of an actual incinerator. We evaluated the case in which the net calorific value (H_u) was temporarily lowered. Hu has a large effect on the combustion condition of an incinerator.

The solid line in **Fig. 6** shows variations in the amount of steam generated after H_u was temporarily lowered , and the dotted line is the simulated results from the model. The response waveforms for the steam generation reduction rate are close enough to conclude that the incinerator combustion model simulates the actual incinerator quite well.

5.3 Design of control system

After verifying that the incinerator combustion model was properly designed, as described in **Section 5.2**, we started running simulations and adjusting control parameters to study the design of the control system using the model.

We constructed the control system to stabilize long-term combustion based on the following fundamental concepts.

(1) A stable supply of refuse is provided for the target incineration volume, as determined by the steam generation settings and H_u. The grate speed is controlled to maintain the volume of refuse remaining in the incinerator as constant as possible.

(2) The ratio of the total combustion air volume to the volume below the grate is mainly controlled by the amount of steam generation. If steam generation becomes less than its set value, the total combustion air volume is increased, and the air ratio allocated below the grate is adjusted to provide more combustion air in the main combustion area to enhance combustion. If the generation of steam becomes greater than its set value, the total combustion air volume is decreased, and combustion air is dispersed to all areas of the grate by decreasing the allocation ratio of air for the main

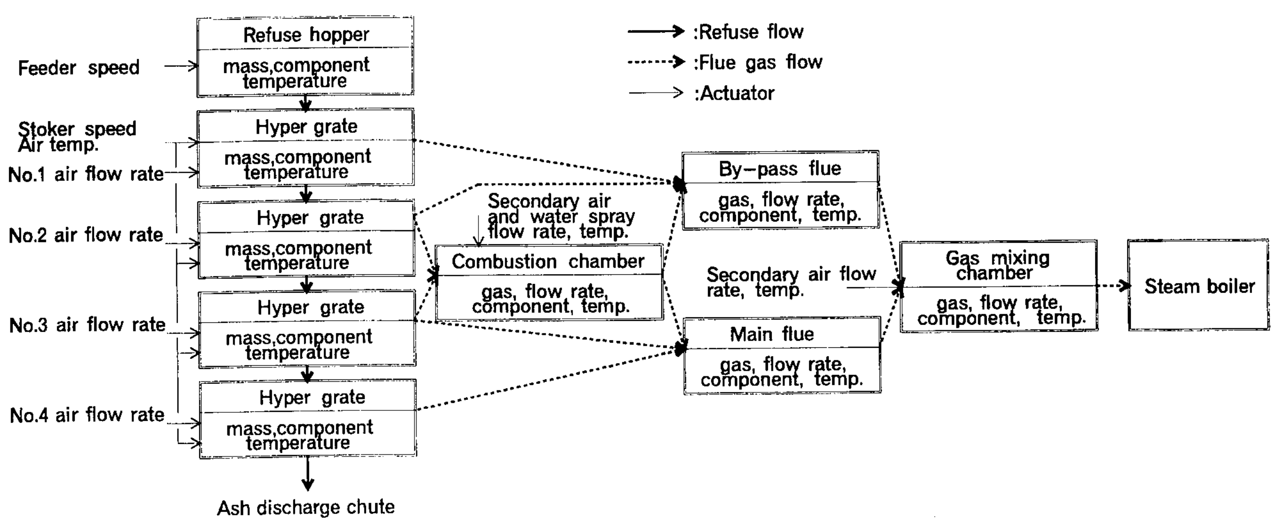

Fig. 5 Structure of mathematical model

combustion area to suppress combustion.

5.4 Simulation of control system

We evaluated the performance of the control system by using the control system constructed in **Section 5.3** to simulate incinerator combustion under the same conditions as used in **Section 5.2**. As shown in **Fig. 7**, variations in steam generation were low regardless of temporary variations in H_u. This indicated that the control system was properly designed.

6. Simultaneous reduction system of CO and NOx by fuzzy control

As shown in **Chapter 5**, the control method based on the incinerator combustion model provided stable combustion regardless of variations in refuse quality and assured that the average, long-term operation remained in Zone II of **Fig. 3**. In the actual incinerator, however, short-term variations occur that could not be expressed by the incinerator combustion model, such as the abrupt changes in CO generation shown in **Fig. 2**. Fuzzy control is appropriate for such strongly non-linear processes.

The fuzzy control system has 5 inputs: CO, NOx, O_2, gas mixing chamber temperature, and secondary air volume. Its output is the set value for the secondary air volume. In **Fig. 3**, R_1 corresponds to each rule

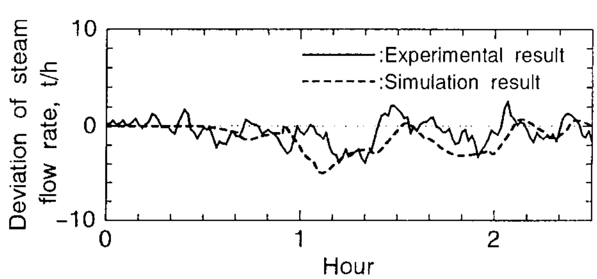

Fig. 6 Responses to change in Hu

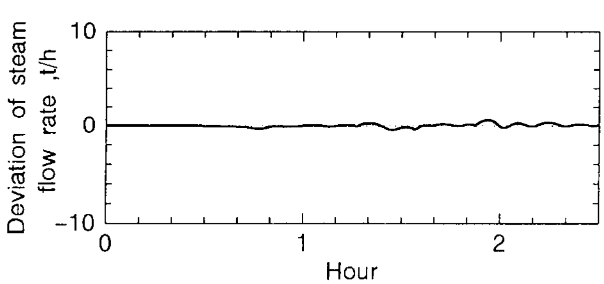

Fig. 7 Simulation result

number in **Table 1**. The arrows in **Fig. 3** show the directions of the secondary air volume as instructed by the rules. The secondary air volume is controlled by rules R_1~R_4 in Zone I, R_5~R_7 in Zone II, and R_8~R_{11} in Zone III.

As a whole, these rules generally maintain the temperature in the gas mixing chamber within the range necessary for complete combustion. They also control the secondary air volume to maintain O_2 at an appropriate concentration. If the concentration of CO or NOx increases, these rules control the secondary air volume to suppress the appropriate component and keep the combustion condition within Zone II, where both CO and NOx concentration levels are kept low.

7. Results of actual incinerator operation

A working incinerator was equipped with the Hybrid ACC system, which combines a long-term combustion stabilization control system based on the modeling and simulation of the incinerator combustion with a fuzzy control system for the reduction of short-term variations in CO and NOx. **Table 2** shows the operational conditions and results of the working incinerator. As an example of the operation, **Fig. 8** shows the time changes of steam generation and CO and NOx

Table 1 Control rules

Rule No.	Input signals (Antecedents)					Output signal (Consequent)
	CO	NOx	O_2	Temp.	Secondary air flow rate	Set value of secondary air flow rate
R_1				High	Small	Negative
R_2				Low	Small	Positive
R_3	High					Positive
R_4			Low			Positive
R_5			High	High	Medium	Negative
R_6			Adequate	High	Medium	Positive
R_7				Low	Medium	Zero
R_8				High	Big	Positive
R_9				Low	Big	Negative
R_{10}		High				Negative
R_{11}			High big			Negative

CO :CO concentration in exhaust gas
NOx :NOx concentration in exhaust gas
O_2 :O_2 concentration in exhaust gas
Temp. :Temperature in gas mixing chamber

concentrations of the 100t/day Hyper Grate type incinerator.

The ACC system stabilized steam generation quite well and suppressed CO and NOx concentrations. No abrupt generation of CO, such as shown in **Fig. 2**, was observed.

8. Conclusion

We designed a Hybrid ACC for long-term combustion stabilization with simultaneous reduction of short-term variations in CO and NOx and installed it in conventional NKK-VϕUND and Hyper Grate type incinerators. As a result, we could reduce the concentrations of CO and NOx simultaneously, stabilizing both their mean and peak values at low levels. We also stabilized the amount of steam generation. This control system is expected to adequately meet future social requirements for the reduction of toxic substances in exhaust gases and the improvement of energy recovery efficiency in electric power generation by waste heat recovery.

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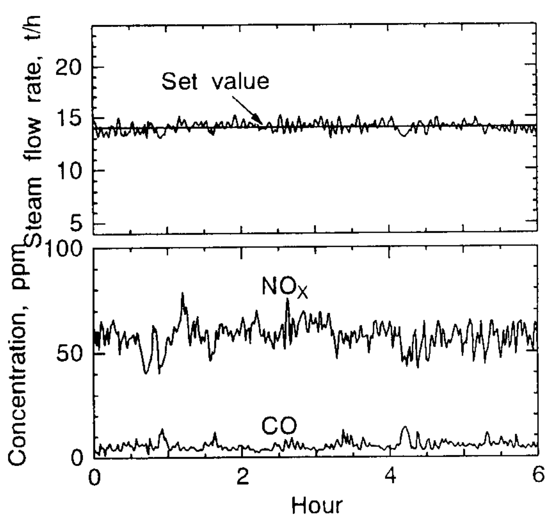

Fig. 8 Operation results with Hybrid ACC

Table 2 Operation results with Hybrid ACC

Operating conditions			Results				
Incineration capacity (ton/day)	Stoker type	Set value of steam flow rate (ton/hour)	Steam flow rate		NOx concentration (O_2 12% conversion)	CO concentration (O_2 12% conversion)	
			Average(t/h)	Standard deviation /ave.(%)	Ave. (ppm)	Ave. (ppm)	Max. (ppm)
100	Hyper grate	14.0	14.0	3.5	58	5.6	15
150	conventional	21.0	20.9	2.9	50	6.7	14
300	conventional	40.0	39.6	3.5	67	6.5	10

NKK Electric-resistance Furnace for Residues from Municipal Solid Waste Incineration Plants

Yoshinari Fujisawa*, Keisuke Nakahara**,
Tsuyoshi Nakao**. Kazuhiro Teratsuji***.
Tetsuo Akashi****, and Hidenobu Hiraoka****

Landfill capacity is decreasing rapidly. The remaining landfill sites in Japan will be used up in about 8 years because of ever-increasing residues from municipal solid waste (MSW). New sites are difficult to find and create for the residues to be landfilled. In addition, the residues contain toxic heavy metals as well as dioxins and requires special detoxification treatment before disposal. The vitrification process can solve these problems by 1) reducing volume of residues and recycling the vitrified products, which can help to reduce the landfill shortage problem, and 2) detoxifying the residues. NKK developed a vitrification technology that uses an electric-resistance furnace. This report introduces the commercial-scale demonstration plant that incorporates the technology and presents the results of plant operations for treating residues from the Kyoto City and Tokyo Metropolitan MSW incineration plants.

1. Introduction

Vitrification is expected to be a leading waste incineration treatment process for the future because it can detoxify the residues from municipal solid waste incineration, such as bottom ash and fly ash, and recycle them as resources[1]. After many years of research and development of vitrification technology[2], NKK established an advantageous electric-resistance furnace process for vitrifying incineration residues that features superior detoxification and utilization of the residues.

NKK conducted continuous operation tests using an experimental, 12 t/d electric-resistance furnace[3]. NKK then performed long-term operational tests using a commercial scale (24 t/d) demonstration plant in joint studies with Kyoto City and Tokyo Metropolis to verify the effectiveness of the process and the operational stability of the plant[4)-7)]. In the operational tests, vitrifying tests of incineration residues from several municipalities were conducted to confirm the effectiveness of the plant independently of the residue source and the safety of the resulting slag when recycled as a resource. The feasibility of using the slag as a resource was validated through aggregate tests of tiles and blocks produced from the slag[5),10)]. The possibility of using dust from the vitrification process (vaporized and condensed materials consisting of salts and heavy metals that are collected at a bag filter) as a raw material for smelting was also demonstrated in the tests[11)].

* Manager, Environmental Plant System Lab., Engineering Research center
** Senior Research Engineer, Environmental Plant System Lab., Engineering Research center
*** Manager, Environmental Plant Engineering and Design Dept.
**** Senior Manager, Environmental Plant Engineering and Design Dept.

This paper describes the results of operational tests of a vitrification demonstration plant with a capacity of 24 t/d with regard to ease of plant operation, the migration behavior of toxic metals, the generation of toxic gases during the detoxification processes, the decomposition of dioxins, the safety and usefulness of slag as a resource, and the feasibility of using dust as a resource.

2. Expectations for vitrification treatment

The demand for vitrification is becoming greater because of increasing concern about the short supply of landfill sites. Previously, simply extending the life of the landfill sites by reducing the total amount of refuse (through vitrification) was considered sufficient. Recently, the demand for vitrification has intensified to eliminate the need for final disposal by detoxifying and recycling the incineration by-products as resources. In particular, utilization of the slag as a safe resource is required. In the past, the most common method for detoxifying toxic metals was based on confining them within a slag. At present, however, from the viewpoint of slag utilization, there is an increasing trend toward detoxification methods such as vitrification method that not only vaporize the toxic metals in the melting process and but recover them in the dust collected at a bag filter for use as a resource. Expectations for vitrification is higher than ever as a method for simultaneously detoxifying toxic metals and dioxins (by thermal decomposition) and recycling the vitrified products as raw material resources, thereby reducing the impact on the shortage of landfill sites.

3. Electric resistance-furnace process

3.1 Electric-resistance furnace

Fig. 1 shows a schematic drawing of the structure and principle of melting of the electric resistance furnace. In the melting furnace used for this process, carbon electrodes are inserted into the thick molten slag layer to apply electric current and maintain the temperature of the molten slag at around 1500 °C. The electric current passes through the molten slag and the slag generates resistance heat, which then heats the ash floating on the slag and dissolves it into the molten slag. The melting furnace is sealed to maintain a reducing atmosphere in the furnace to prolong the electrode life. The metals in the charged ash and those generated from the furnace reduction reactions settle and form a molten metal layer just beneath the molten slag layer because of their differences in specific gravity. The molten slag and the molten metals are discharged from their individual taps using the head pressure.

3.2 Electric-resistance furnace process

Fig. 2 shows a flow diagram of the electric-resistance furnace process. The plant comprises ash charging hoppers, a melting furnace, a combustion chamber for the furnace exhaust gas, a dust collector, and a solidification unit for slag and metals. Exhaust gas from the melting furnace is treated by combusting the CO and H_2 gas components in the combustion chamber, and then removing the dust using a bag filter unit. The remaining gas is then vented into the atmosphere. The molten slag is treated either by air or water cooling. Crushed slag is obtained by air treatment, while sandy slag is formed by water-granulation treatment. The molten metals are recovered in ingot form by air cooling.

3.3 Features of the electric-resistance furnace process

The electric resistance ash melting furnace differs from other melting furnaces in terms of the furnace structure and melting method. The differences include

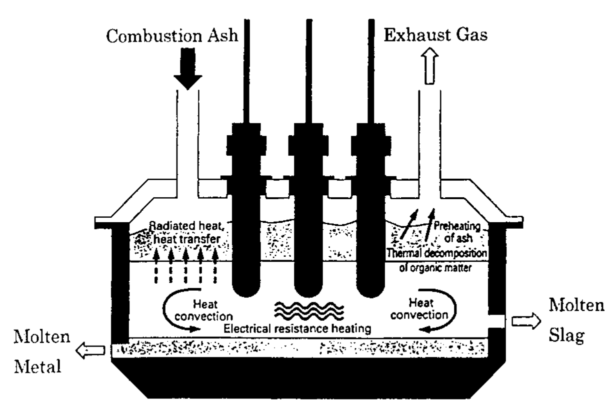

Fig. 1 NKK electric-resistance furnace

a layer of charged ash (ash layer covering) over the molten slag layer, a thick molten slag layer, individual slag and metal ash discharge tapping holes, and reducing furnace atmosphere. Specifically, therefore, the electric-resistance furnace process has the following characteristics.

(1) Ease of operation

・The slag viscosity does not need adjustment, and auxiliary materials do not need to be added, because of slag's long furnace retention time.

・Ash melting in a reducing atmosphere reduces the consumption of electrodes.

・The mild melting kinetics emit less noise.

・The quantity of scattering ash in the furnace and ash carried by the exhaust gas is less, reducing the quantity of emitted dust.

・The molten slag layer is thick, which makes it possible to accommodate fluctuations in the composition of charged ash.

・The quantity of exhaust gas generated from the melting furnace is less.

・The quantity of HCl, SOx, and NOx emissions are less.

(2) Detoxification of the residues from waste incineration

・Use of the reducing atmosphere provides complete decomposition of dioxins.

・Toxic metals such as lead are vaporized and then concentrated in the dust collected at the bag filter.

(3) Properties and utilization of slag as a resource

・The slag does not contain metal inclusions because separate layers of slag and metal are formed due to their difference in specific gravity, and because the molten slag and metal are discharged through separate tapping holes.

・The slag has no ash inclusions because the molten slag is discharged directly from the molten slag layer through its tapping hole.

・The slag has less toxic metals because the toxic metals evaporate by the reaction in the reducing atmosphere.

・The slag has a uniform composition with lower inclusion of toxic metals because of its long furnace retention time.

・The slag elutes only an extremely small quantity of toxic metals and thus a high level of safety is assured when it is used as a construction material.

・Composition can be adjusted in response to slag usage.

・Crushed slag and sandy water-granulated slag are both produced.

(4) Properties and utilization of dust as a resource

・The dust has a high zinc and lead content, and can be used as a resource.

・Water-washing of the dust easily provides a concentrated zinc and lead product.

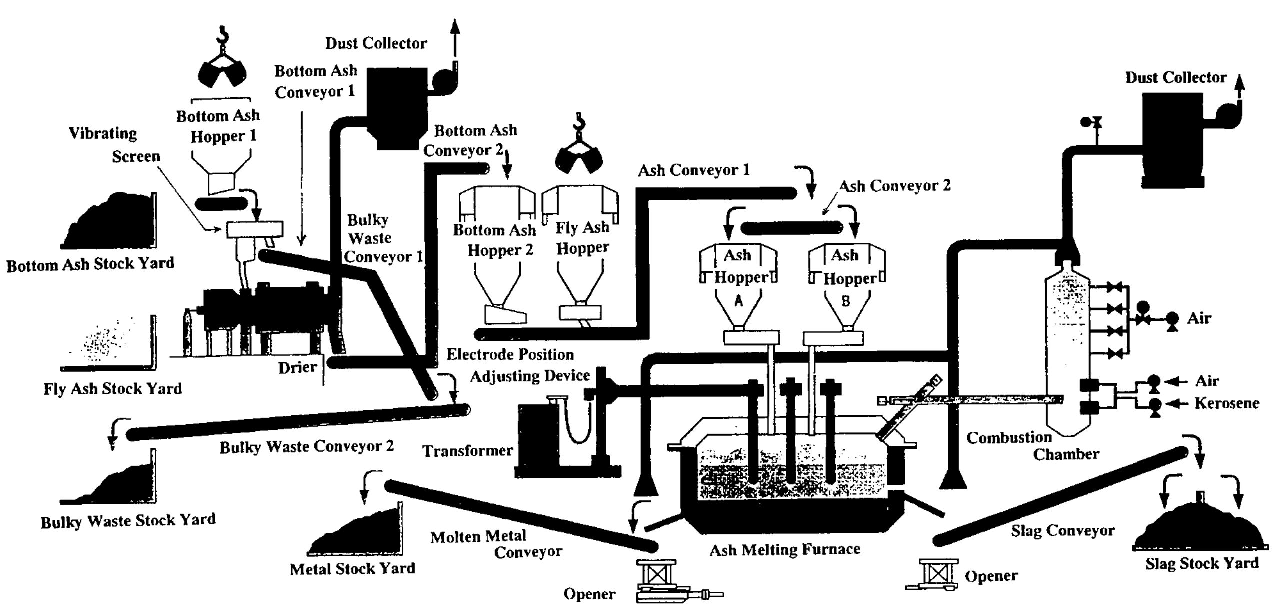

Fig. 2 Flow diagram of NKK ash vitrification process (for demonstration)

4. Demonstration operational test

A series of continuous operational tests for vitrifying bottom ash and mixed bottom ash and fly ash were conducted using the electric-resistance furnace demonstration plant. This section presents an example of the bottom ash vitrifying test (CASE 1)[5] and two examples of mixed vitrifying of bottom ash and fly ash (CASE 2[4),6)], CASE 3[7)]).

4.1 Test procedure

4.1.1 Test plant

The tests were conducted at the 24 t/d demonstration plant, as shown in the flow diagram in **Fig. 2**. The demonstration plant is capable of continuous operation covering steps from ash acceptance, melting, and exhaust gas treatment to slag and metal solidification. Specifications of the ash melting furnace are given in **Table 1**.

4.1.2 Ash used for tests

Table 2 shows examples of chemical analysis of the incineration ash residues used for the tests. All ashes for CASEs 1 to 3 were taken from typical 24 hour continuous stoker furnace incineration processes. CASE 1 only used a bottom ash. CASE 2 used a bottom ash and a fly ash (an EsP ash - a fly ash from an electrostatic precipitator (EsP) - obtained after passing through a wet type hydrogen chloride removal unit). CASE 3 used a bottom ash (including a fly ash that was treated by a clinker channel together with the bottom ash) and a fly ash (an EsP ash obtained after passing through a dry type hydrogen chloride removal unit). The bottom ash was screened to remove large lumps and was adjusted to a water content of approximately 4-6% by drying before the tests. The fly ash was not treated before the tests. The mixing ratio of the bottom ash and the fly ash was in accordance with their generation ratio.

Table 1 Specifications for demonstration furnace

Furnace Type	NKK electric resistance furnace
Capacity	24 t／day
Furnace Outer Dimension	3.9 m (diameter), 1.9 m (height)
Electrode	Carbon 0.2 m (diameter)
Transformer Capacity	1100 kVA

4.2 Test results

4.2.1 Operation

A long period of stable operation was verified for melting both the bottom ash and the mixed bottom ash and fly ash. In CASE 1, 1340 tons was treated over a total of 111 days, and in CASE 2, 760 tons was treated over a total of 33 days. CASE 3 also provided smooth operation, although the test period was rather short because of a limited ash supply. Ash melting consumed electric power at about 860 kWh/t-ash at a 24 t/d ash charging rate, and the electrode consumption at that ash charging rate was about 1 kg/t-ash. In addition, the durability of refractories was confirmed to be one year or longer.

4.2.2 Material balance

The generation rate of slag, metals, and dust depends on the composition of the charged ash. **Fig. 3** shows an example of the balance of material for CASE 2. For CASEs 1 through 3, the slag generation was 70

Table 2 Chemical composition of residue from MSW combustion furnace

Element		CASE 1	CASE 2		CASE 3	
		Bottom Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash
Si	mass %	25.0	15.0	10.3	17.6	15.0
Al	mass %	9.0	9.5	6.3	8.3	7.9
Ca	mass %	6.5	13.7	10.2	15.6	14.5
Mg	mass %	0.75	1.2	1.4	1.5	1.7
Fe	mass %	12.0	10.3	2.3	5.5	1.4
Na	mass %	1.4	2.1	7.7	1.7	3.3
K	mass %	0.30	0.85	6.2	0.97	3.8
Cl	mass %	0.37	1.6	12.0	1.2	7.4

to 80% of the charged ash quantity, and the metal generation was 4 to 15%. The dust generation was 1% for bottom ash melting (CASE 1), and 2 to 4% for the mixed melt of a fly ash containing a large amount of salts and a bottom ash (CASE 3).

5. Detoxification and utilization of waste incineration residues as resources

The following findings were obtained from results of the demonstration tests with regard to detoxification and utilization of incineration residues as resources.

5.1 Vitrified products composition and migration behavior of major elements

Table 3 shows examples of the chemical analysis of slag, metals, and dust generated in CASEs 1 through 3. The elements are listed in order of content for each melt product.

Slag: Si, Ca, Al >> Na, Fe
Metal: Fe >> Cu > Si, P
Dust: Cl, Na, K, Zn > Pb

The compositions show a characteristic migration behavior during melting. For example, the migration ratio of the major elements into the slag, metal, and dust for CASE 3 is given in **Fig. 4**. All of the Si, Al, Ca, and Mg, and most of the Na and K migrated into the slag. Most of the Cu, a large portion of the Fe and P, and part of the Pb migrated into the metal. All of the Cd and most of the Pb and Zn migrated into the dust. The migration behavior of elements is affected by the melting environment (oxidizing or reducing)[9].

5.2 Safety and utilization of slag as construction material resources

The slag contains only a very small amount of toxic metals such as Pb and Cd[8]. This is because melting in the electric-resistance furnace is conducted in a reducing atmosphere, and the slag remains in the furnace for a sufficiently long time, as long as 10 hours or more, during which the heavy metals not only vaporize, but also form a metal layer or migrate into the metal layer. Therefore, the slag itself contains a very small amount of heavy metals[9].

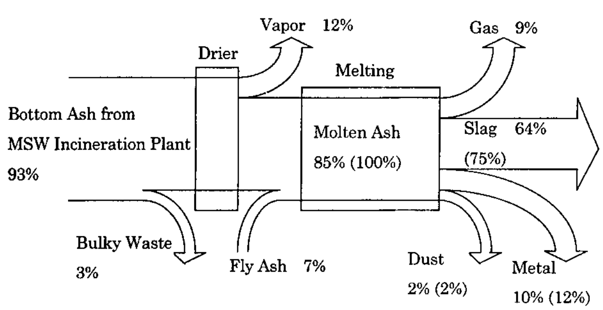

Fig. 3 Material balance (CASE 2)

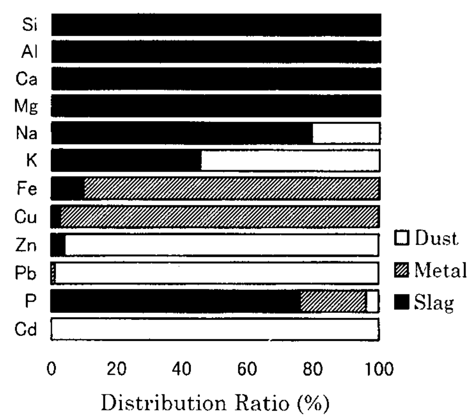

Fig. 4 Migration ratio of elements (CASE 3)

Table 3 Chemical composition of products from electric-resistance furnace

Element		Slag			Metal			Dust		
		CASE 1	CASE 2	CASE 3	CASE 1	CASE 2	CASE 3	CASE 1	CASE 2	CASE 3
Si	mass%	23.7	21.3	17.0	3.85	1.72	0.60	0.23	0.57	0.67
Al	mass%	10.8	10.4	11.5	<0.01	0.03	<0.01	0.26	0.23	0.16
Ca	mass%	11.4	10.9	21.0	0.02	<0.01	<0.01	0.37	0.16	0.54
Fe	mass%	1.29	6.47	0.46	84.7	92.2	91.0	0.75	0.69	0.09
Na	mass%	4.50	4.43	2.10	<0.01	<0.01	<0.01	12.3	16.1	11.7
K	mass%	0.94	1.18	0.80	<0.01	<0.01	<0.01	9.4	13.0	20.4
P	mass%	0.024	0.34	0.41	2.65	2.35	2.30	0.043	0.044	0.44
Cu	mg/kg	120	200	99	58700	52100	77000	1100	1400	2600
Pb	mg/kg	<10	72	<10	1000	2750	500	100000	64000	41000
Zn	mg/kg	175	1660	370	1300	1760	480	270000	214000	189000
Cd	mg/kg	<0.5	<0.5	<0.5	<10	<10	<0.5	1000	3100	4100

To determine the elution of toxic metals from the slag, leaching tests were conducted in accordance with Notification No. 46 of the Environmental Agency, which provides environmental standards for soil. The results are listed in **Table 4**. As seen in the table, the slag satisfied the environmental standards for soil. **Table 5** shows the characteristics of air-cooled slag as aggregate. The air-cooled slag satisfies the standard values for road construction and concrete aggregates. Thus, use of the slag for a wide range of practical applications in construction fields was verified to be feasible[5)-10)].

5.3 Utilization of dust as a resource

In the dust, Pb accounts for 4 to 7% and Zn 18 to 25%. The sum of Pb, Zn, Na, K, and Cl accounts for 85 to 95%. The content of Si, Al, and Ca of the dust is less because scattering ash and carried-in ash are not mixed into the dust and because Si does not vaporize during melting. Since the dust comprises water-soluble NaCl and KCl, and nearly insoluble ZnO, PbO, and $PbCl_2$, a water-washing treatment can dissolve NaCl and KCl to readily leach out concentrated Zn and Pb. **Table 6** shows the results of a water-wash test for the dust. After the water-washing treatment, 51% of the ash is Zn, and 16% is Pb. The treated ash can likely be recycled as an intermediate material for a simultaneous lead/zinc smelting process (e.g., Imperial Smelting Process)[11)].

5.4 Properties of gas at exit of melting furnace and combustion chamber

Table 7 shows examples of chemical analysis of gas at the exit of the melting furnace and combustion chamber. The gas from the melting furnace was combusted in the combustion chamber to reduce the CO content to less than 5 ppm. The gas contained low levels of SOx, NOx, and HCl that equal to the lowest level results previously reported[1)]. The HCl content in the gas at the exit of the combustion chamber was as low as 30 to 60 ppm. The low HCl content can be explained as follows using eqs. (1) and (2) that show typical reactions for forming HCl : there is a low probability for the occurrence of reaction (1) because the SOx content of the gas at the exit of the melting furnace was as low as less than 3 ppm; and there is also a low probability for reaction (2) to occur because SiO_2 and Al_2O_3 existed in solid phase and are not melted, resulting in a low reaction rate. Therefore, we concluded that HCl formation is low in the electric-resistance furnace process[6)].

$$2NaCl + H_2O + SO_2 + 1/2O_2 \rightarrow 2HCl + Na_2SO_4 \quad ......(1)$$

$$2NaCl + H_2O + 2mSiO_2 + Al_2O_3 \rightarrow 2HCl + 2NaAl\,Si_mO_{(2+2m)} \quad ......(2)$$

Table 4 Leaching test on molten slag

Item	Unit	Result			Regulation
		CASE 1	CASE 2	CASE 3	
Hg	mg/l	<0.0005	<0.0005	<0.0005	0.0005
As	mg/l	<0.005	<0.005	<0.005	0.01
Se	mg/l	<0.002	<0.002	<0.002	0.01
Cd	mg/l	<0.001	<0.001	<0.001	0.01
Pb	mg/l	<0.005	<0.005	<0.005	0.01
Cr^{6+}	mg/l	<0.04	<0.04	<0.04	0.05
pH	-	7.2	8.2	10.0	

Specified by EPA, Japan
(Environment Protect Agency Notification No.46)

Table 5 Properties of molten slag

Item	Molten Slag	Aggregate Standard for Road-Crushed Rock-Class1	Aggregate Standard for Concrete
Specific Gravity	2.68	>2.45	>2.5
Moisture Absorption Rate [%]	0.06	<3.0	<3.0
Abrasion loss [%]	34.1	<35	<40
Stability [%]	<1		<12
Corrected CBR [%]	99		

Table 6 Leaching effects on dust from melting furnace

Element	Dust from M.F. mass %	Treated dust mass %
Na	12.9	0.70
K	12.7	0.21
Pb	6.1	15.8
Zn	21.5	51.4
Cu	0.20	0.24
Sn	0.32	0.52
Cl	32.9	2.6

5.5 Decomposition of dioxins

Fig. 5 shows an example of the behavior of dioxins in a vitrification plant for CASE 3. The melting furnace had a reducing atmosphere, and the decomposition rate of dioxins was almost 100%. Although the observed decomposition rate for the whole plant was 99% or more, a decomposition rate closer to 100% is expected for the whole plant by optimizing combustion chamber conditions to further diminish the slight amount of dioxins remaining in the dust.

6. Conclusion

A series of long-term, continuous operation tests using a commercial scale, 24 t/d, electric-resistance furnace, ash vitrification plant verified the safety and the stability of the plant. Consideration was given to detoxification such as the migration behavior of toxic metals during melting, generation of toxic gases, and decomposition of dioxins. Consideration was also given to the safety and utilization of slag as a resource, and to the possibility of recycling the dust as a resource. As a result, the following characteristics of the electric-resistance furnace process were verified.

(1) Detoxification and utilization of incinerated waste residues as resources

- Toxic metals are concentrated in the dust ; thus, the dust can be used as a resource.
- The slag contains less toxic metals and induces less elution of toxic metals, so it is very safe for use as a construction material.
- The slag is free from inclusions of metals and ash; thus, its quality as a resource is high.
- Dioxins are detoxified by thermal decomposition.

(2) Safety and stability of the plant

- Less toxic gas is emitted during melting.
- Safe and stable operation of continuous melting is assured for bottom ash and for mixed bottom ash and fly ash.

We would like to express our appreciation to the staff at Kyoto City and Tokyo Metropolis for their support and help in conducting the demonstration test of the electric-resistance furnace process.

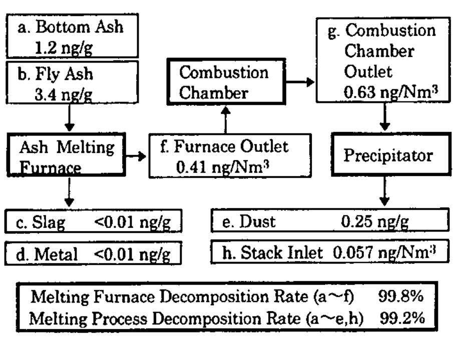

Fig. 5 Behavior of dioxin (dioxins are shown by I-TEQ)

Table 7 Properties of exhaust gas from melting furnace and combustion chamber

Item	Unit	Furnace Outlet			Combustion Chamber Outlet		
		CASE 1	CASE 2	CASE 3	CASE 1	CASE 2	CASE 3
Flow Rate	wet Nm^3/h	230	210	140	970	690	300
Temperature	℃	340	695	420	810	743	640
H_2O	%	40.7	29.3	26.3	9.4	9.9	12.6
CO_2	dry %	21.0	31.6	21.6	4.8	11.5	11.4
O_2	dry %	1.1	0.8	<0.1	16.7	10.7	10.5
CO	dry %	43.7	26.2	39.8	<5ppm	<5ppm	<2ppm
H_2	dry %	4.9	23.1	27.8	<0.1	<0.1	<0.1
HCl	dry ppm	60	60	88	27	48	58
SOx	dry ppm	5	<3	<3	7	<3	<3
NOx	dry ppm	<5	10	9	58	50	80
Dust	g/Nm^3	57	47	44	19	14	20

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Pre-sorting Technologies in a Waste Recycling System

Makoto Arimoto*, Keishi Akiu**,
Toshio Takuwa***, Eiji Oshida****,
Youichi Yoshinaga***** and
Motoyuki Asano******

NKK developed a waste recycling system – a sorting and recovery system for recyclable waste such as glass bottles, plastic bottles, steel cans, aluminum cans and other residue. This system incorporates a combination of different sorting and recovery equipment, including a bag breaker & remover, compressed air sorter, and aluminum/PET bottle, plastic, and color-based glass-bottle separators. This paper primarily describes the pre-sorting equipment in the new sorting and recovery system, including the bag breaker and high performance, compressed air sorter.

1. Introduction

The increased volume of municipal waste in recent years and the difficulties in finding new sites have resulted in a shortage of treatment and final disposal sites. On the other hand, the "Packaging Waste Recycling law" was enforced in April 1997, and the infrastructure designed for a waste-recycling society that incorporates environmental considerations has been developed. Considering this background, the demand for technologies for higher-level recycling is expected to increase further.

However, the intermediate processes for recycling municipal waste remain very labor intensive, and improvements in the working environment and the increase in the processing capacity need urgent attention. NKK has actively developed technologies to automate the sorting and recovery process of waste for recycling and has accumulated considerable knowledge regarding individual components for such systems and regarding system design. The experience gained in the development culminated in the commercial operation of a recycling facility begun in March 1997 for the Central Environmental Hygiene Association of Haga-gun in Tochigi Prefecture. The facility comprises automated equipment for separating steel cans, aluminum cans, and PET bottles, and for sorting glass bottles by color. Prior to this project, NKK constructed a pilot plant for the recycling system[1] at NKK Environmental R&D Center in September 1996 to develop needed sorting and recovery technology.

This paper mainly describes the pre-sorting technology used in the waste recycling system and reports the results of a performance evaluation of the system.

* Manager, Environmental & Recycling Plant Planning Center
** Assistant Manager, Environmental & Recycling Plant Planning Center
*** Environmental & Recycling Plant Planning Center
**** Manager, Control Engineering Research Dept., Applied Technology Research Center
***** Senior Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
****** Research Engineer, Control Engineering Research Dept., Applied Technology Research Center

2. Pre-sorting technology

Waste discarded by the large number of residents in an area is likely to contain a variety of unexpected items, the range of which is extremely difficult to predict. The wide variety of waste must first be "pre-sorted" with some degree of uniformity to ensure a sufficient level of performance of sophisticated sorting equipment such as the automated equipment to sort glass bottles by color.

NKK's sorting and recovery system shown in **Fig. 1** consists of the following processes: of which processes (1)~(4) are referred to as "pre-sorting".

(1) A bag breaking process to tear open and empty bags of rubbish

(2) A removal process to remove items unsuitable for recycling

(3) A magnetic separation process to remove items of iron and steel, etc.

(4) Sorting and recovery processes to separate glass bottles from aluminum cans, PET bottles, and plastic films, etc. using a compressed air sorter, and then to sort and recover them using a round-items separator

(5) A sorting process to sort glass bottles by color

(6) A separation process to recover aluminum cans from the mixture of aluminum cans and PET bottles that remains after compressed air sorting

(7) A separation process to remove chlorinated plastics from other plastic waste.

3. System components

3.1 Bag breaker

NKK's bag breaker is shown in **Photo 1**. The bag breaker is located at the beginning of the recycling system and empties the contents of the bags. It consists of two saucer-shaped disks, each with a series of equally-spaced blades around the periphery. The two disks are located in the same plane and rotate in opposite directions. When a bag enters the space between the disks, the blades pull the bag and tear it apart by its rotating movement, emptying the bag of its contents. The opening of the bags is shown in **Photo 2**.

Specifications for the bag breaker are given in **Table 1**. The unique feature of this machine is that it tears open the bag by pulling it apart, eliminating most of the breakage of bottles, etc., commonly observed with conventional methods that use a crushing force. In addition, the rapid speed at which the machine operates allows large volumes of waste to be processed in a short time[2].

3.2 Equipment for removal of items unsuitable for recycling

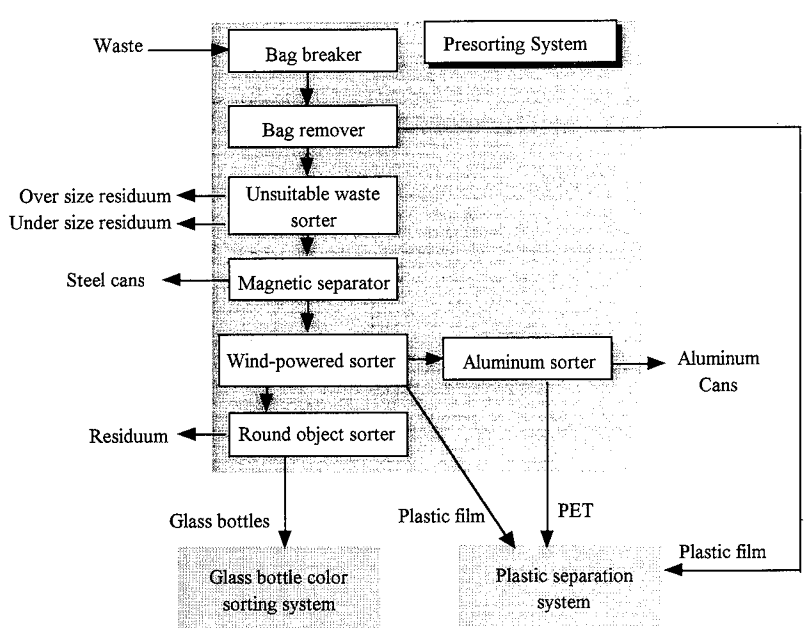

Fig. 1 Automated waste sorting and recovery system

This equipment uses vibration to sift the waste and removes all items smaller than 40 mm and larger than 150 mm. Items smaller than 40 mm include batteries, stones, and glass fragments, while items larger than 150 mm include gas canisters and discarded cooking utensils and pans, which are too large to be handled in the downstream equipment. The equipment is shown in **Photo 3**.

3.3 Compressed air sorter

3.3.1 Characteristics of the equipment

This equipment is the core element of the pre-sorting technology. After steel cans are removed with the magnetic separator, the waste is sorted by its weight into heavy (glass bottles), medium (aluminum cans, PET bottles), and light (plastic film). The waste is blown by the air and is sorted according to its distance from air nozzles. Compressed air is used, so the volume of air moved is only 1% of that used by conventional methods. This eliminates the need for a cyclone and dust collector. The equipment is therefore more compact and less expensive to construct than conventional types. Specifications for this equipment are shown in **Table 2**.

3.3.2 Principles of operation

Cans and bottles were previously considered to be unsuitable for air blowing sorting for the following reasons.

(1) The sorting accuracy is greatly affected by the shape of the items, and as a result sorting accuracy is low.
(2) It is difficult to generate a uniform flow, and as a result sorting accuracy is low.
(3) The need for a cyclone, bag filter and other auxiliary equipment leads to high construction costs.

To overcome these disadvantages, NKK developed a sorter that uses a compressed air blast. The compressed air provides much higher energy per unit area, blowing the items greater distances with less air. Also, the optimized positioning of air nozzles provides uniform air flow.

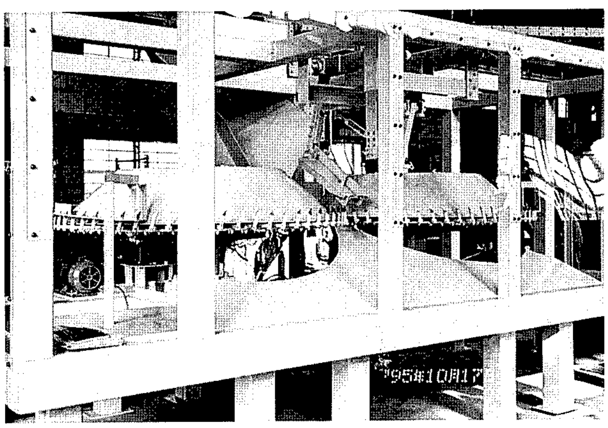

Photo 1 Bag breaker

Table 1 Bag breaker specifications

Type	Twin saucer type
Weight	3700kg
Saucer diameter	ϕ 1330mm
Saucer speed	Max 30rpm
Power Unit	2.2kW×2
Throughput	45bags/min (14ton/h)
Glass breaking ratio	Under 5%

Photo 2 Opening plastic bags with the bag breaker

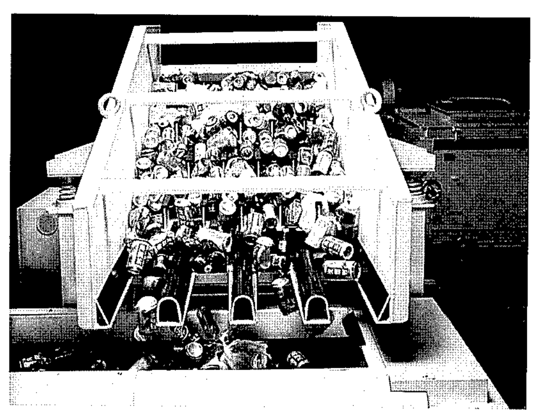

Photo 3 Equipment for removal of nonrecyclable waste

With conventional air blowing sorters, the distance an item is blown depends on its projected area, so that the sorting accuracy for items such as crushed cans is quite low. In the design of NKK's compressed air sorter, the effective area of the blast from the nozzles is smaller than the projected area of all items to be sorted. This makes the sorting accuracy high, regardless of the shape[3].

3.3.3 Equipment configuration

The compressed air sorter is shown in **Photo 4**. Waste is fed into the equipment from a vibrating feeder, which separates the items from each other. Each piece of waste is blown by the compressed air blast to a distance that is inversely proportional to its mass; so items with the highest specific gravity fall into the nearest chute, aluminum cans and PET bottles fall into the intermediate chute, and plastic film and paper, etc. fall into the far chute (they are blown onto a mesh screen type conveyor, which then carries them until they fall into the far chute).

3.3.4 Compressed air sorter performance

The results of sorting waste with glass bottles, aluminum cans, PET bottles, plastic film and other garbage are shown in **Fig. 2**. More than 95% of the items recovered in each of the three chutes were as required, with the content of the farthest chute being almost 100% plastic film. No crushed aluminum cans were found in the nearest chute, and all were recovered in the intermediate chute.

Table 2 Compressed air sorter specifications

Type	High pressure wind-powered sorter	
Throughput	6ton/h	
Utility	Compressed air ($3kgf/cm^2$, $3Nm^3/min$)	
Performance	Heavy	Glass bottles; Purity 98%
	Medium	Al. Cans, PET bottles; Purity 98%
	Light	Film, Paper; Purity 100%

3.4 Round items separator

Glass bottles recovered in the nearest chute (for the heaviest) then enter the round items separator. This unit uses an inclined conveyor to separate round items and remove items unsuitable for recycling such as ashtrays made of crystallized glass and ceramics, raising the proportion of glass bottles that are recyclable.

3.5 Aluminum cans and PET bottles separator

Aluminum cans and PET bottles recovered in the intermediate chute are sorted using an eddy current separator.

4. Pre-sorting performance trial using actual waste

4.1 Trial conditions

A trial run of the pre-sorting equipment was conducted using actual municipal waste. The composition

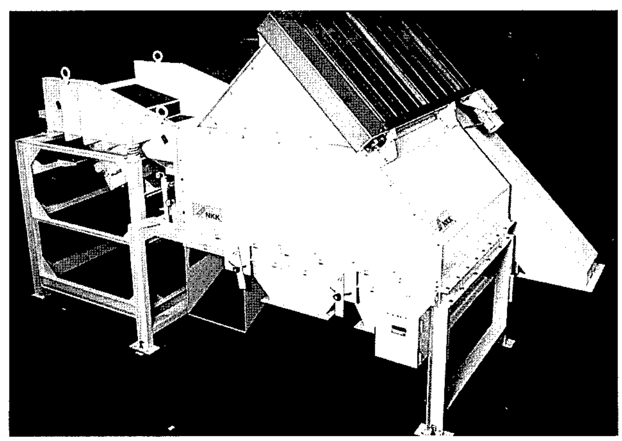

Photo 4 Compressed air sorter

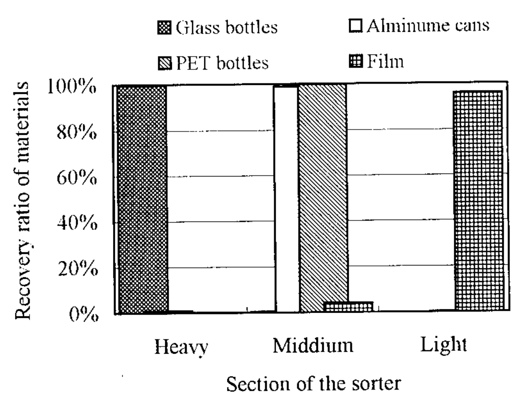

Fig. 2 Compressed air sorter test results

of the waste is shown in **Fig. 3**. The waste was collected in bags, approximately 60% of which split during collection, with some of the contents falling out. About 30% of the glass bottles were already broken, and the waste contained a considerable number of nonrecyclable items, such as discarded cooking utensils, toys, and unopened cans. The equipment operated at a processing speed of 6 tons of waste per hour.

4.2 Trial results

The purity(sorting accuracy) rate and recovery rate for each separated item type are shown in **Table 3**. The rates are defined as follows.

$P = W_r / (W_r + W_{err})$

$R = W_r / W_{input}$

Note :

P: Purity

R: Recovery rate

W_r : Amount of items recovered correctly in the chute

W_{err} : Amount of incorrect items recovered in the chute

W_{input} : Amount of total waste fed into the pre-sorting equipment

A few steel cans were mixed with the aluminum cans because the steel cans were not correctly removed by the magnetic separator (probably because plastic film had become attached to the separator). Glass fragments in the recovered glass bottle container were counted as impurities, so the figure is slightly lower than would otherwise be the case. The recovery rate for glass bottles was quite high at 88% because the whole system including the bag breaker, is designed to minimize breakage.

5. Conclusion

This paper describes NKK's unique pre-sorting technology. The technology combines a number of elemental technologies with advanced features and provides very high sorting accuracy. In the future, the demand for recycling is expected to increase, which in turn will raise the demand for more sophisticated and diversified methods for waste recycling. By further expansion and development of the elemental technologies and their incorporation into systems, we will provide sophisticated total systems that can flexibly suit a wide variety of customer requirements.

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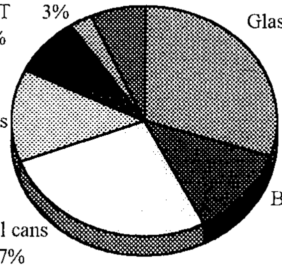


Fig. 3 Waste composition

Table 3 Purity and recovery rates

Material	Purity (%)	Recovery ratio(%)
Glass bottles	95%	88%
Steel cans	93%	95%
Al. Cans	99%	86%
PET bottles	83%	99%
Film	100%	—

Pre-sorting Technologies Employed in NKK's RDF System

Takashi Yokoyama*, Seiichi Abe**,
Yoshinari Fujisawa***, Eiji Oshida****,
Youichi Yoshinaga***** and Motoyuki Asano******

NKK developed an RDF system that uses a ballistic separator and an air classifier to separate combustibles from household waste. In this paper, we describe the ballistic separator and our presorting system that are used for producing RDF.

1. Introduction

Solid fuel that is produced by compressing and solidifying municipal solid waste to facilitate storage and transport is referred to as RDF (Refuse Derived Fuel). Since RDF produces electric power more efficiently than that generated from recovered heat using conventional refuse, RDF is gradually gaining acceptance as a method for the waste treatment.

The following technical points must be considered in the production of RDF.
(1) Remove incombustible materials, which result in ash after incineration.
(2) Transform as much of the combustible content as possible into RDF to minimize residue.
(3) Recover useful materials from the waste.
(4) Maintain stability in operation in spite of variations in the quality of the waste.
(5) Maintain stability in operation in spite of the presence of foreign materials in the municipal waste.

To satisfy these conditions, the system must allow storage, drying, sorting, transport, and solidification to be combined in a manner suitable to the quality and the end use of the RDF.

NKK has undertaken research and development on the next generation of refuse processing technology and constructed a demonstration plant at its Environmental R&D Center at the Tsurumi site in Yokohama City. Operation of the demonstration plant for the production of RDF began in September 1996, and considerable data has been collected since then.

Current work involves the construction of a presorting system for the removal of incombustible materials from municipal waste by using a ballistic separator and the operation of a demonstration plant for producing RDF.

2. The ballistic separator

2.1 Sorting principles

The trajectory of an item after it collides with a plate is determined by such factors as its density, shape, and hardness. This property is used as the basis of the

* Manager, Environmental Industries Engineering Div., Environmental Plant Engineering and Design Dept.
** Environmental Industries Engineering Div., Environmental Plant Engineering and Design Dept.
*** Manager, Eco-technology Lab, Kawasaki Research Center
**** Manager, Control Engineering Research Dept., Applied Technology Research Center
***** Senior Research Engineer, Control Engineering Research Dept., Applied Technology Research Center
****** Control Engineering Research Dept., Applied Technology Research Center

ballistic separator, which is shown in **Photo 1**. The technology was obtained from the Australian company Innovative Pte. Ltd.

The principle of the ballistic separator is shown in **Fig.1**. The mechanism is extremely simple - it consists of a plate, referred to as a paddle, mounted at an angle and vibrated by crankshafts.

When unsorted refuse is fed onto the vibrating paddle, hard objects (e.g., metal) bounce and reach the bottom of the slope regardless of the vibration frequency. Light and soft objects (e.g., plastic film, fabric) do not bounce and migrate to the top of the slope by the vibration of the paddle. This process acts to separate heavy and light objects, as well as to break up lumps of refuse, and smaller objects can be separated by fitting a screen to the paddle. Three types of objects may be separated, as shown in **Table 1**.

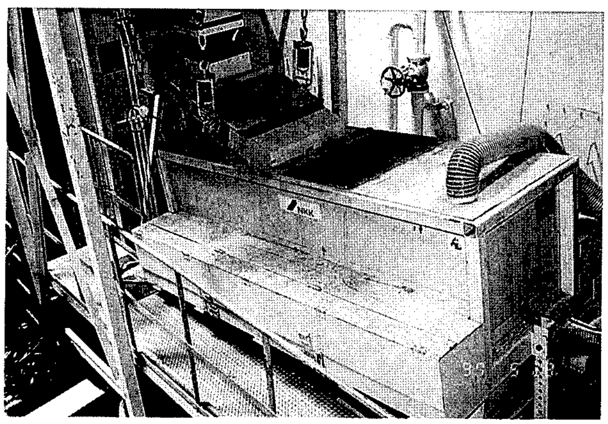


Photo 1 Appearance of the ballistic separator

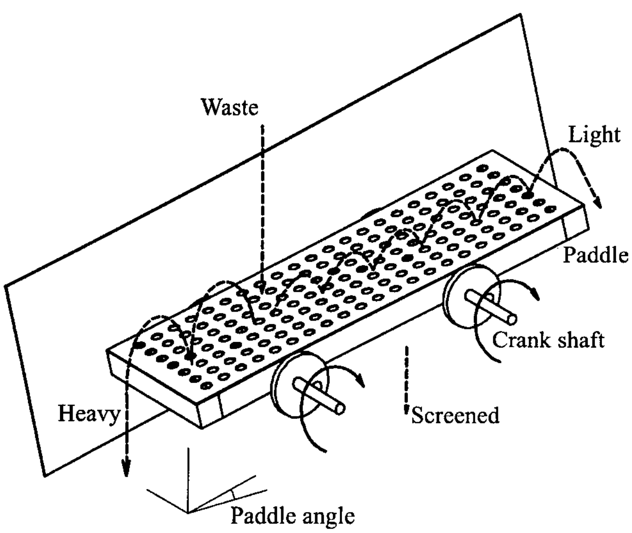


Fig. 1 Principle of the ballistic separator

The characteristics of the sorter are as follows.

(1) Performance is relatively consistent despite variations in the amount of refuse fed to the paddle.
(2) The structure of the sorter is simple, robust, and highly reliable.
(3) The crankshafts are not exposed under the paddle and therefore do not become entwined with fabric, etc., which can result in reliability problems.

2.2 Tests to determine sorter characteristics

2.2.1 Test outline

Tests were run to determine the characteristics of the ballistic sorter with various types of refuse.

Specifications for the separator used in the tests are shown in **Table 2**. The parameters that determine sorting performance are the paddle angle (paddle slope) and the paddle speed (crankshaft rpm), as shown in **Table 1**. The sorter used in the tests was capable of continuous operation at speeds between 103 and 206rpm and paddle angles of 0 ~ 9° in 1° increments. Specifications for the refuse samples used in the tests are shown in **Table 3**.

Table 1 Parameters of the ballistic separator

Categoly	Material	Parameter
Heavy	metal. solid plastic. rubber etc.	Inclined angle Paddle speed
Light	paper. film.	
Screened	soil. metal. stone. peaccs of china. peace of glass. lumber. etc..	Screen size

Table 2 Specification of the ballistic separator

Type	Ballistic separator
Capacity	$5m^3/h$
Power unit	1.5kW
Paddle rotation	103rpm ~ 206rpm
Number of paddles	1pcs
Screen size	20mm

2.2.2 Test results

Fig.2 shows the proportion of each sample recovered at the top of the paddle. The smaller the paddle angle, and the greater the paddle speed, the easier it is to recover light objects at the upper side. The performance in recovering heavier objects was satisfactory at paddle angles of 6 ~ 9°. Almost all metal lumps, particularly bolts and nuts, were removed at a paddle angle of 9°. A minimum of 95% of lighter objects such as paper and plastic film were recovered at paddle speeds of 160rpm and higher.

These tests showed very good results for sorting both light and heavy objects. Intermediate weight objects such as cardboard boxes and Styrofoam trays had good results as well. These are relatively light, while being somewhat elastic, and are recovered with either the light or heavy objects, depending on the paddle rpm and angle.

With any type of material, the recovery rate increases with paddle speed only up to a certain limit, after which it remains almost constant. Therefore, the paddle angle has a major effect on sorting.

Use over a wide range of applications is possible by setting the paddle speed and angle of the ballistic separator to suit the quality of the refuse and purpose of sorting. The use of a number of such sorters in combination, or its use in combination with an air classifier, permits the optimization of a sorting system for any specific purpose.

Future construction of such sorting systems requires the accumulation of a database of a wide variety of knowledge in this field.

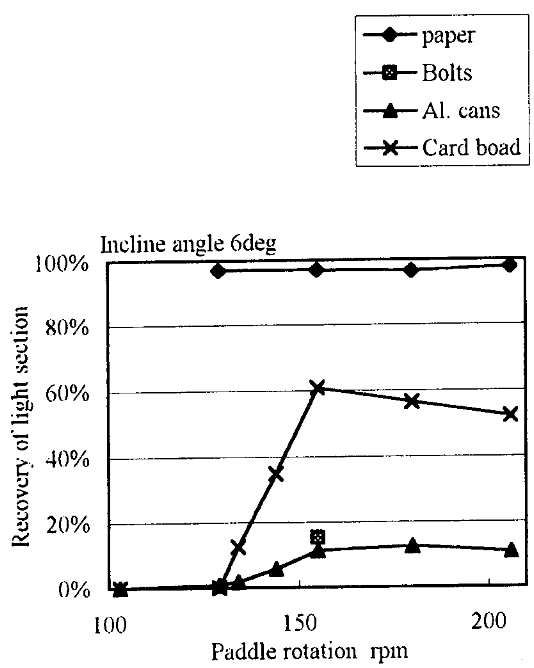
Table 3 Experimental conditions

Paddle angle	6 ,9°
Paddle speed	103rpm ~ 206rpm
Screen size	φ 20mm
Samples	Paper(□100mm)
	Plastic film
	Card board
	PS plate
	Alminum cans
	Bolt Nut

3. Applications of the RDF pre-sorting system

3.1 RDF system flow

The process by which RDF is produced in NKK's demonstration plant is shown in **Fig.3**.



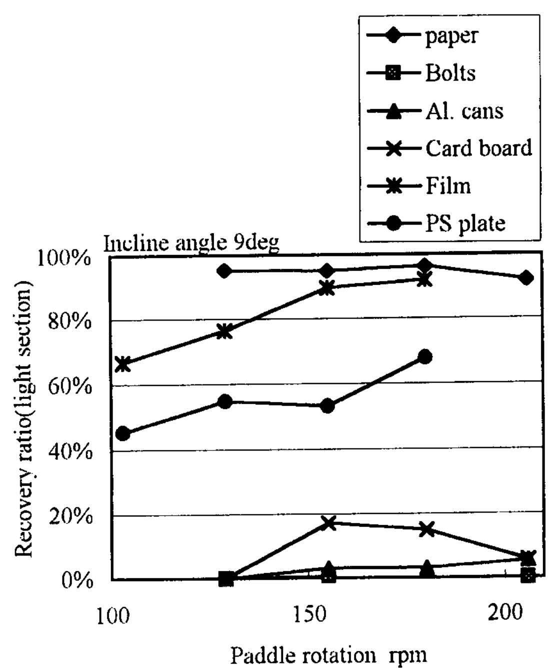


Fig. 2 Experimental results

Waste refuse stored in the pit passes through the primary shredder, after which it is dried. The drying process reduces the moisture content of the refuse to approximately 10%. In Japan, waste refuse generally contains 40~60% moisture, which is considerable higher than that in Europe and the USA. The initial drying process is therefore included to improve the accuracy of sorting.

The dried refuse is then passed to a vibrating feeder, which supplies it at a uniform rate to the ballistic separator. The separator then divides the dried refuse into the following three types.

(1) The heavy waste consists primarily of metal objects and hard plastic. In NKK's demonstration plant, the hard plastic items have a high chlorine content and are therefore removed because they are unsuitable for RDF at NKK. However, such items can be included, depending upon the intended use of the RDF.

(2) Garbage, wood scraps, sand, stones, glass, ceramics, electrical cables, and wire, etc., are recovered as small items and may be further sorted into light and heavy items in a vertical air classifier. The screen size of the paddle is set at ϕ20mm to obtain the appropriate particle size for subsequent stages in the process.

(3) The light objects consist of paper, plastic film, and fabric. These are passed through a secondary shredder, where they are cut up to the required particle size. The cost of maintenance for the shredder blades is greatly reduced because other hard objects such as metals and stones are already removed.

The small objects from the air classifier and the light objects from the secondary shredder are mixed and compressed into blocks.

3.2 Operating results

NKK's demonstration plant started producing RDF from general municipal waste in October 1996. Subsequent operation confirmed the performance of the pre-sorting system in removing incombustible materials from the refuse.

Fig.4 shows the composition of the dried refuse prior to sorting.

Approximately 3% of the municipal waste was unsuitable for RDF (i.e., metal and ceramics), but the iron content of the RDF (as determined by elemental analysis) was 0.29%, which confirms the effectiveness of the pre-sorting system.

4. Conclusion

This paper described the features of the ballistic separator technology introduced by NKK. This sorter uses a simple principle to provide highly efficient sorting of light and heavy objects and is expected to find extensive application in the future.

The combination of the ballistic separator and the Air Classifier was used in NKK's demonstration pre-sorting plant, and trials confirmed its performance to be as designed.

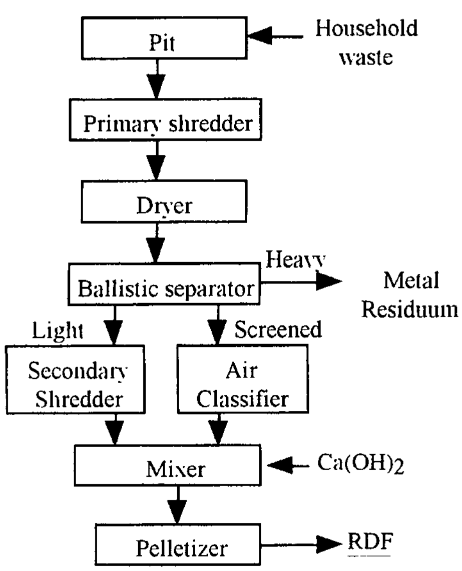


Fig. 3 RDF system flowchart

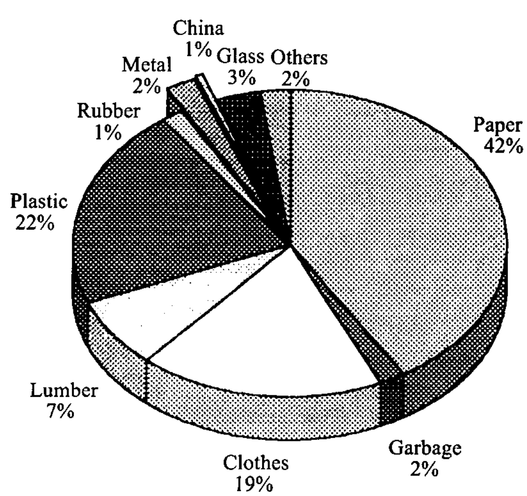


Fig. 4 Composition of household refuse

NKK RDF (Refuse Derived Fuel) Production System

Takashi Yokoyama*, Hatsuo Uehara*,
Seiichi Abe**, Keiichi Okuyama***,
and Motoyuki Asano****

NKK recently developed a Refuse Derived Fuel (RDF) Production System as a technology for utilizing municipal solid waste. This system consists of the production processes of shredding, drying, fractionation and pelletizing and has demonstrated good fractional performance. Numerous tests have been conducted through all four seasons of the year in the 20 tons per day RDF pilot plant at NKK's Tsurumi Works. Combustion tests on RDF produced by the pilot plant were also conducted to verify the effectiveness of this system.

1. Introduction

The amount of municipal solid waste produced is increasing each year along with the advances of Japan's economy, and the annual production of waste has reached five hundred million tons. Conventional waste disposal was mostly either incineration or landfill. However, the calorific value of waste is becoming higher due to increasing amounts of plastic waste, and serious problems concerning final disposal sites and the environmental pollution generated by incineration are highlighted in our society. Accordingly, there is an expected demand in society to change attitudes towards waste from "simply incinerate and landfill" to "recycle and utilize as resources."

NKK has responded to these demands and developed various environmental plants, such as a boiler attached to an incinerator, an ash melting furnace system and an automated waste sorting and recovery system. In addition, the NKK RDF Production System, which recycles waste into Refuse Derived Fuel (RDF), was recently developed. An RDF pilot plant was constructed at the NKK Environmental R&D Center in Tsurumi in May 1996, and the plant has been in operation since September 1996. Various proof tests were conducted throughout the four seasons to obtain various operational and test data. This paper describes an outline of the system, as well as the pilot plant, and presents the results of the verification tests. This paper also reports the results of experiments in which RDF produced in the system was burnt in a fluidized bed incinerator.

2. Composition of NKK RDF production system

The basic flow of the system is illustrated in **Fig. 1**. The concept in developing this system was to "separate combustibles from incombustibles effectively and accurately." The following process was set up to achieve this.

* Manager, Environmental Plant Engineering and Design Dept.
** Environmental Plant Engineering and Design Dept.
*** Senior Research Engineer, EnvironmentalPlant Lab, Kawasaki Research Center, Applied Technology Research Center
**** Control Engineering Research Dept., Applied Technology Research Center

(1) Fine shredding to enhance the drying effectiveness and fractionation accuracy (primary shredding)
(2) Drying prior to fractionation
(3) Sorting in two stages (primary and secondary fractionation)

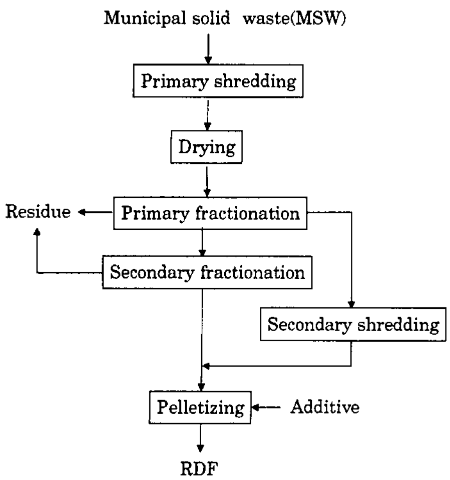


Fig. 1 Flow of NKK RDF system

3. Outline of pilot plant

An outline of the pilot plant, which was designed in line with the basic process flow, is described below. The flow of the pilot plant is illustrated in **Fig. 2**.

(1) Name: RDF Production System Pilot Plant
(2) Address: 2-1 Suehiro-cho, Tsurumi-ku, Yokohama-shi
(3) Target: Municipal solid waste (Waste)
(4) Capacity: 20 tons of waste per day (16 hours)
(5) Commencement: September 1996
(6) Area: Approx. 400m² (excluding the pit)

3.1 Primary shredding

It is difficult to determine the composition of waste, and all sorts of articles are assumed to be mixed together. No all-purpose shredder exists, so the most suitable shredder needs to be selected. The main selection criteria are described below:

(1) Grain size after shredding: less than approx. 50 mm

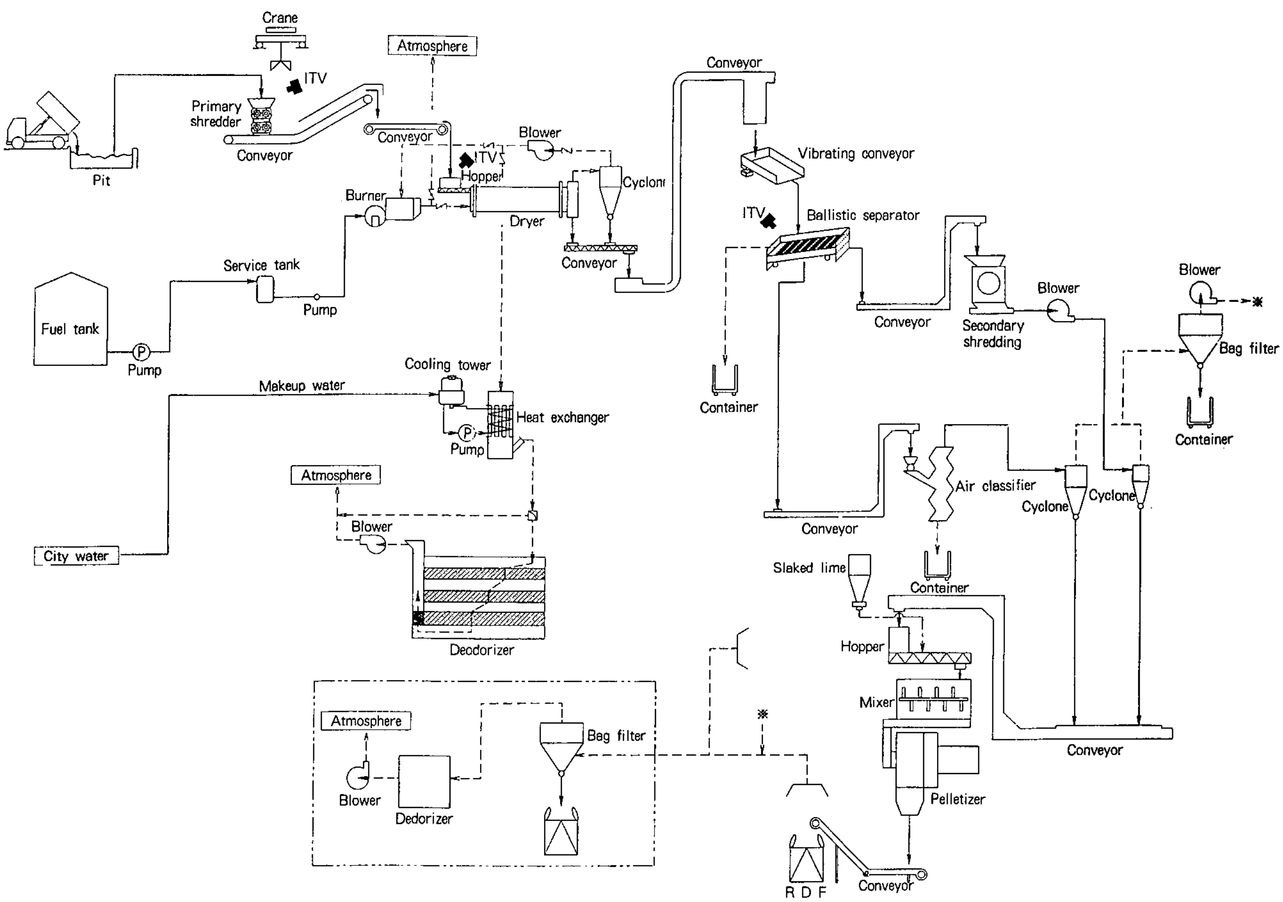


Fig. 2 Flow of NKK RDF pilot plant

in diameter

(2) Durable against hard objects such as metal chips

The plant adopted double-stage shredders that are equipped with separate cutting shafts and rotate slowly.

3.2 Drying

As indicated in **Table. 1**, waste generated in Japan is generally high in water content, even though the composition varies between areas. Therefore,

(1) in order to produce high strength RDF, and

(2) to prevent the decomposition of RDF,

the water content in the waste needs to be reduced. Furthermore, waste with low water content is less likely to decompose or to stick to components such as the transporting conveyor. For that reason, drying has positive effects, such as:

(3) reducing bad smells inside the plant, and

(4) improving the working environment during maintenance.

The plant has a rotary drier that uses kerosene for fuel. The drier consists of a slow-speed rotating furnace with stirring blades that rotate at high speed at the center of the furnace. This mechanism stirs the waste. While stirring, the waste directly contacts the hot air generated by the burner and moves forward. The waste is dried to a water content of less than 10%.

Table 1 Composition of raw waste

Item	Unit	'96.10	'97.3
Apparent specific gravity	ton/m^3	0.12	0.2
Moisture	Wet%	37.7	42.1
Ash	Wet%	15.5	9.5
Combustible	Wet%	46.9	48.4
Higher heating value	kcal/kg	2470	2480
Lower heating value	kcal/kg	2060	2040
Paper	Dry%	55.8	65.3
Kichen waste	Dry%	3.5	1.1
Cloth	Dry%	5.8	2.2
Garden waste	Dry%	3.7	5.8
Plastic	Dry%	18.7	15.6
Rubber·Leather	Dry%	1.4	0.2
Metal	Dry%	4.8	5.1
Stone	Dry%	0.6	0.5
Glass	Dry%	2.0	1.4
Others	Dry%	3.7	2.9

3.3 Fractionation

As shown in **Table 1**, materials such as metal, rock and glass in the waste are unsuitable for fuel. For the production of RDF, these objects must be removed to the extent possible. However, the removal of combustible objects along with unsuitable ones also needs to be avoided as much as possible. For instance, combustible articles such as clothing and groceries may contain metallic parts, such as buttons, zippers, springs and reinforcing materials. The following procedure was set up to remove such metal parts and produce RDF from the residue.

(1) The waste is shredded into fine pieces, and combustibles are separated from incombustibles.

(2) The shredded waste is dried to prevent the incombustibles from sticking to the combustible particles due to moisture in the waste.

(3) Multiple fractionation devices are combined and systematized to enhance fractionation accuracy.

Furthermore, the following fractionation devices are adopted.

Primary fractionation device:

(4) a ballistic separator that utilizes differences in how objects bounce

Secondary fractionation device:

(5) a blast separator that utilizes differences in the specific gravity of objects

An outline of the ballistic separator is illustrated in **Fig. 3** (For details of the ballistic separator, refer to "Pre-sorting Technologies Employed in NKK's RDF System" in the same edition).

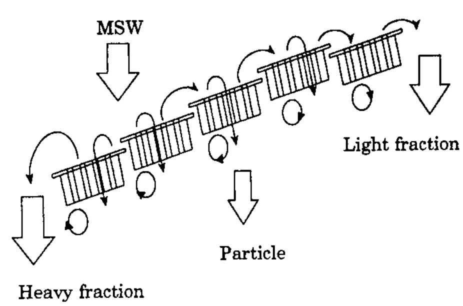


Fig. 3 Schematic at ballistic separator

3.4 Secondary shredding and pelletizing

A ring-die method was adopted for pelletizing waste in order to produce consistent, high-strength RDF. As illustrated in **Fig. 4**, the waste is crushed between the high-speed rotating ring-die and the roller. In this process, the waste is compressed and formed by the frictional force between itself and the holes while being forced through the holes in the ring-die. The ring-die is easy to change in this method, and a suitable ring-die can be selected according to the type of waste. This easily produces high strength RDF. However, there is a correlation between the production capacity and factors such as the type and size of waste and the diameter and thickness of the ring-die. In the experiment, three ring-die types with diameters of 5, 10 and 15 mm were used, and the characteristics of each type was monitored. For high strength RDF, as shown in **Photo 1**, the RDF surface turns black by the heating caused by the friction. Furthermore, secondary shredding was performed by a high-speed, single-shaft, rotating shredder to increase the shredding efficiency and enhance the pelletizing performance.

4 Result of tests

Table 2 shows the operational data obtained from the tests conducted for autumn and winter waste. Approximately 1% hydrated lime was added to the waste to suppress the generation of harmful gas during RDF combustion and to limit the decomposition of RDF. The fuel consumption of winter waste was higher than that of autumn waste due to differences in the water content, although the consumption of electric power was similar. These results indicate that, by drying the waste immediately after shredding, differences in the load due to the water content for each device after fractionation were eliminated.

Operational data for the verification tests are shown in **Table 3**. Stable production of RDF with nearly equal calorific value and a water content of less than 10%

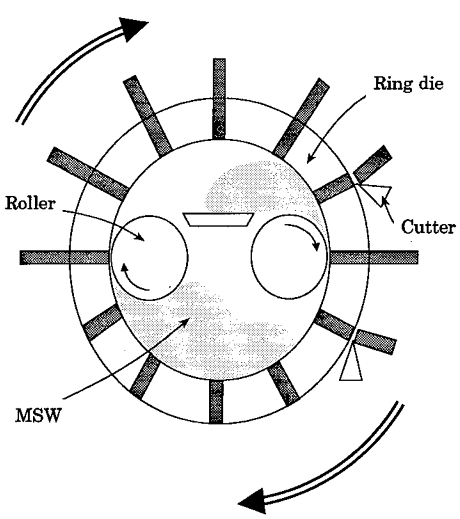
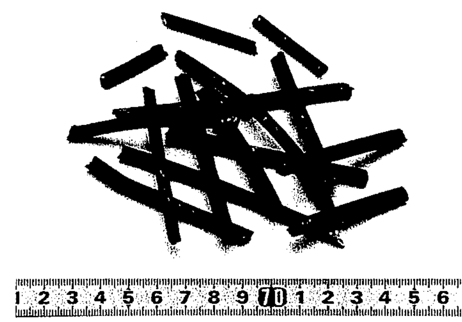
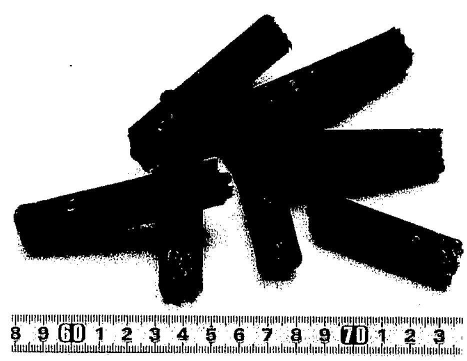


Fig. 4 Schematic at pelletizer



ϕ5



ϕ15

Photo 1 RDF

Table 2 Operating data

Item	Unit	'96.10	'97.3
Quantity of used fuel	ℓ/h	34.9	44.0
	ℓ/ton-MSW	26.4	34.1
Quantity of producing RDF	kg/h	824	667
Quantity of used MSW	kg/h	1322	1290
Quantity of used power	kW	130.5	134.5
	kW/ton-MSW	98.7	98.8
Quantity of used slaked lime	kg/h	13.2	12.9

was achieved for a ratio of 50% against the waste in the tests. The RDF composition is shown in **Table 4**. Furthermore, the combustion test of the RDF was conducted in a fluidized bed incinerator. The result of the combustion test is shown in **Table 5**. The chemical composition of the combustion exhaust gas does not indicate any particular problem. The content of dioxins, which have recently become a social issue, was low at 0.5 mg-TEQ/Nm^3 at the incinerator outlet, which verified stabilized combustion characteristics. Combustion tests using a total of 125 tons of RDF were conducted in a cement kiln, demonstrating the usefulness of RDF as cement fuel.

Table 3 Operating experience

Item	Unit	'96.10	'97.2~3
Operating time of NKK RDF pilot plant	h	239	119
Quantity of used MSW	ton	305	153

Table 4 Composition of RDF

Item	Unit	'96.10	'97.2
Apparent specific gravity	ton/m^3	0.5	0.6
Moisture	Wet%	9.1	9.8
Higher heating value	kcal/kg	4360	4120
Lower heating value	kcal/kg	4010	3800
Ash	Dry%	15.1	16.4
Volatile component	Dry%	72.5	69.8
Fixed carbon	Dry%	12.4	13.8
C	Dry%	44.0	49.9
H	Dry%	6.0	5.7
N	Dry%	0.9	1.0
S	Dry%	0.2	0.1
Cl	Dry%	0.7	0.7
O	Dry%	33.0	26.2

Table 5 Effect of burning RDF

Item	Unit	Value
NOx	ppm	49.5
SOx	ppm	0.7
HCl	ppm	12.8
CO	ppm	<10
Dust	mg/Nm^3	40
DXN	ng-TEQ/Nm^3	0.5*

* Measured value of the exit from the furnace

5. Conclusion

The effectiveness of the NKK RDF Production System was confirmed through verification tests. RDF system plants have been constructed at more than ten locations around the country as a technology for thermally recycling waste. Furthermore, since the dioxin guidelines were tightened by the Ministry of Health and Welfare, small and medium size municipalities are examining the possibility of introducing an RDF system because they are facing difficulties with energy recovery and exhaust gas problems caused by incinerators. The popularization of RDF systems is expected to accelerate in the future. In turn, NKK, using its environment-related and incineration technologies, will continue to actively propose the use of RDF and will strive towards the reduction of future environmental degradation.

Pneumatic Refuse Transportation System

Hidetsugu Nogita*, Kazuhiko Hirotsu**,
and Fuyuki Inoue***

NKK has extensive experience in pneumatic refuse transportation systems and developed and improved a system adopting this method to the transportation of refuse in Japan. This report introduces NKK's pneumatic refuse transportation system by describing the system at Yebisu Garden Place and outlining current developments.

1. Introduction

A pneumatic refuse transportation system was developed by AB Centralsug in 1961, and a full-sized plant started operation in Sweden around 1967. Since then, many plants have been introduced with satisfactory results in Europe and America. In Japan, the first plant was built in the first half of the 1970s, and at present, 26 plants, both large and small, have operated.

Two types of pneumatic refuse transportation system plants prevail. One is a large-diameter plant that has a pipe diameter of 500 to 600 A. This type was introduced into large-scale developments on the initiative of the government, such as the Tsukuba Academic New Town, Yokohama Minato Mirai 21, Makuhari New Center, Tokyo Waterfront Subcenter, and the like. The other type is a small-diameter plant that has a pipe diameter of 150 to 250 A and is equipped with a refuse crusher. This type is suitable for single and composite buildings that generate about 2 to 5 t of refuse per day.

NKK has carried out independent technical development to improve pneumatic refuse transportation systems so that it is suitable for refuse in Japan. NKK has delivered small-diameter plants to Omori Bell Port, Hotel New Otani, etc. and large-diameter plants to Nagaoka New Town, Makuhari New Center, etc.

This report introduces NKK's pneumatic refuse transportation system by using the refuse treatment facility at Yebisu Garden Place, which is thought to be a model facility in future redevelopment plans, as an example. Yebisu Garden Place is Japan's largest-scale redevelopment area developed by private enterprise and functions as a city, including offices, hotel, department store, museum, residences, and so on. This report also describes future trends for pneumatic refuse transportation.

2. Pneumatic refuse transportation system at Yebisu Garden Place

2.1 Background of system introduction

A beer brewery was built at Yebisu in 1887, and its operation ended in 1987, just after 100 years. Yebisu Garden Place was completed in September of 1994 in the area where the Yebisu beer brewery once stood, after a design and construction period of 10 years.

In developing Yebisu Garden Place with its new city functions, a new, ideal refuse treatment system was

* Team Manager, Specialized Waste Treatment System Sales Dept.
** Section Manager, Environmental Plant Plannig and Project Dept.
*** Team Manager, Environmental Plant Plannig and Project Dept.

investigated by holding meetings that started in the planning stage with the Tokyo Metropolitan Bureau of Public Cleaning, Meguro Ward, Shibuya Ward, residents in the area, etc.

The refuse treatment system study was based on the development idea of Sapporo Breweries Ltd., the extensive experience of Kume Sekkei Co., Ltd., and the know-how of NKK. At Yebisu Garden Place, we intended to effectively use resources and provide a people-friendly refuse treatment system. Therefore, bottles, cans, paper, etc., were thought to be recycled, and space for recycling was studied at the planning stage, even before the law promoting the use of regenerated resources (generally called the Resource Recycling Law) was put in force,. Also, treatment methods were studied that were suitable both for municipal solid waste generated in large quantities and for a large variety of relatively small quantities of resources. Mechanization was developed for refuse generated in large quantities to increase the efficiency of refuse treatment. The facility was studied so that refuse requiring careful classification could be sorted easily at its source.

The pneumatic refuse transportation system was introduced on the basis of this idea.

2.2 Features of the system

Yebisu Garden Place is mainly composed of 10 buildings. The refuse generated from these buildings is collected at one place by using a pipeline. It is classified by type and collected in containers, where the refuse can be sorted more thoroughly and the efficiency of refuse transportation can be increased. **Fig.1** shows the general arrangement.

Variations in the quantity of generated refuse are reduced because the refuse generated from 10 buildings is collected. This not only reduces the storage space for each building, but also for the whole facility. Also, because all refuse is collected at one place, refuse treatment for the whole facility can be controlled easily. Further, the use of a large container increases the transportation efficiency about three times over that with a general refuse collection car.

Four types of refuse loading doors are provided

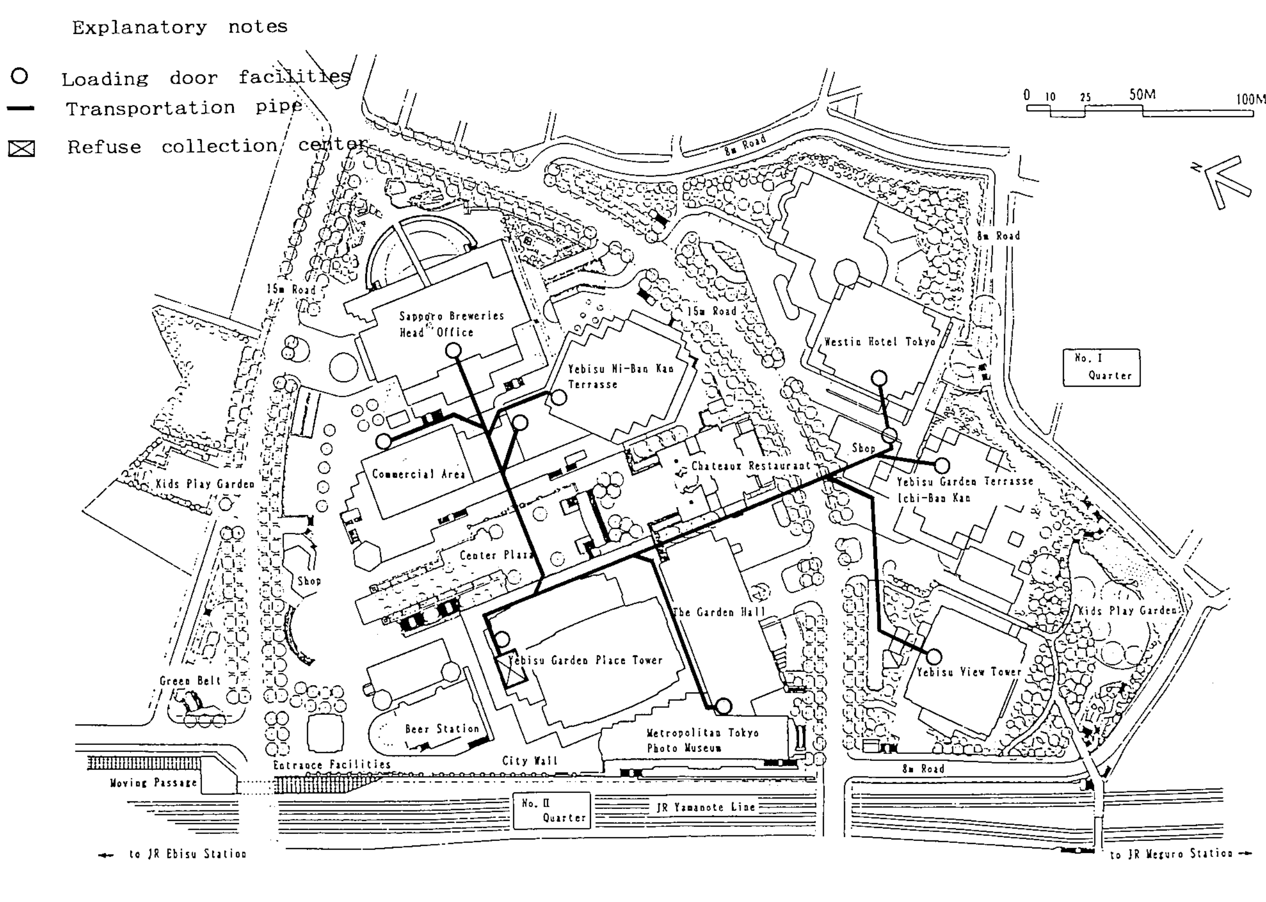


Fig. 1 Overall layout

to classify the refuse thoroughly. This allows the refuse to be loaded at any time, which increases the convenience and promotes recycling awareness.

For resources that are not transported pneumatically, the recycling percentage is increased by the arrangement of classification bins and the security of resource storage space.

2.3 System operation flow

The pneumatic refuse transportation system consists of a series of refuse transportation facilities that can store about 16 t of refuse per day. The refuse generated from the residences, offices, and business buildings, such as the hotel and department store, is pneumatically transported to a collection center on the fifth floor of the Garden Place Tower basement, a total distance of about 1 km. The 500A diameter, refuse transportation pipe is laid under the ground and empties into a container for final delivery. **Fig.2** shows the system flow.

As shown in the system flow diagram, refuse loading doors are provided in each building. The refuse loaded through the loading door is held in a storage device. Therefore, refuse can be loaded at any time without being affected by the refuse collecting operation. The collecting operation starts automatically in a preset treatment schedule. First, an air inlet valve is opened in the building from which the refuse is collected, and air flow is produced in the refuse transportation pipe by a blower. A discharge valve is then opened to move the refuse into the refuse transportation pipe. The refuse is conveyed to the collection center by the air flow. The transported refuse is separated from the air by a refuse separator, and the refuse is compacted and put into a container. The container is conveyed from the container yard on the fifth floor of the basement to a container station on the second floor of the basement by a container shifter and special-purpose container lift. It is carried out of the site

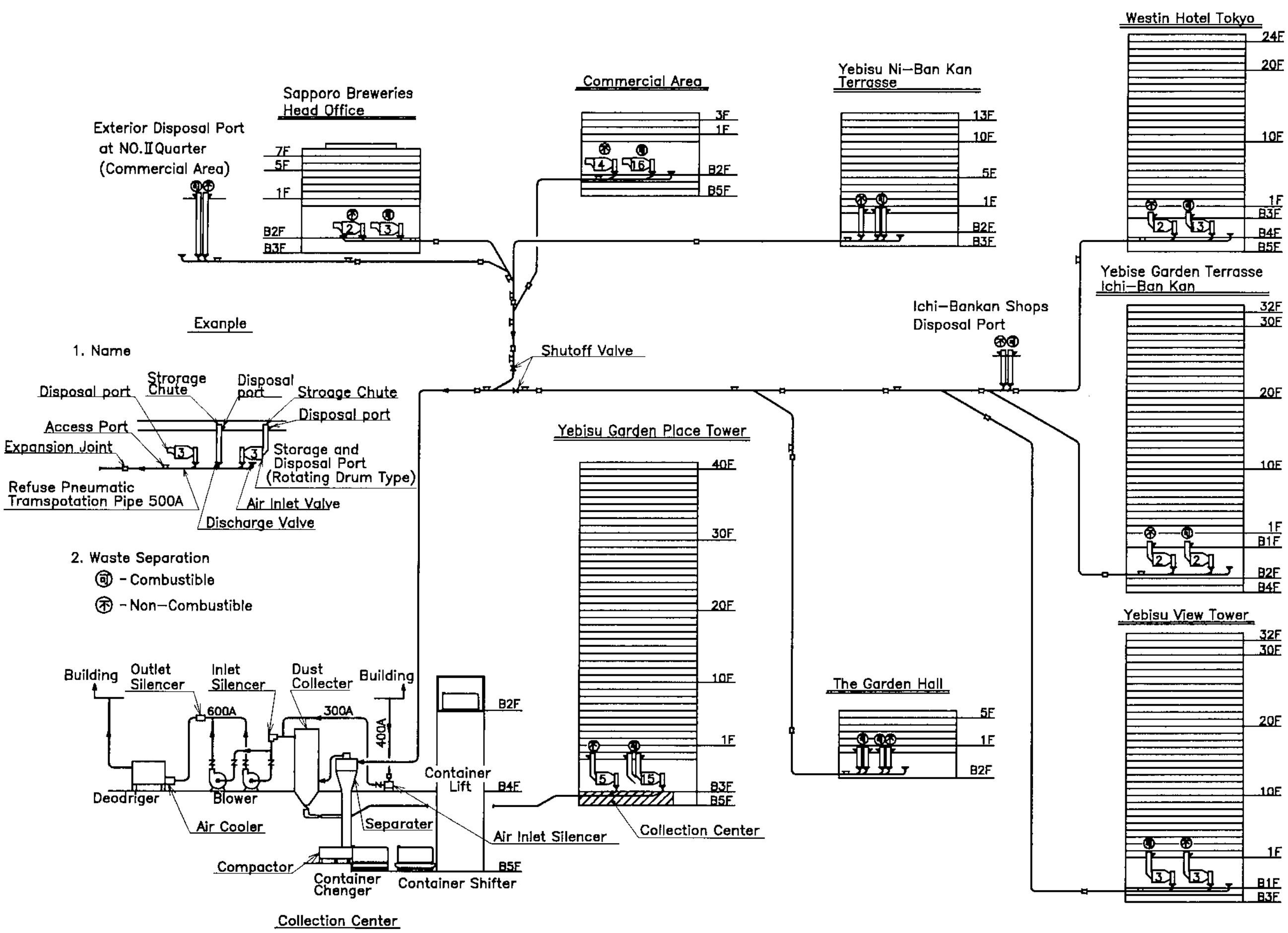


Fig. 2 System flow diagram

in a container transportation car.

The air that is separated from the refuse is discharged to the atmosphere after dust is removed by a dust collector. The air passes through the blower, and then a silencer and an activated carbon deodorizer.

Photo 1 shows the refuse loading door, **Photo 2** shows a storage and discharge unit, **Photo 3** shows the container yard, and **Photo 4** shows a central control unit.

2.4 Collection of classified refuse

The classified refuse is collected separately using different loading doors for each refuse type. Five kinds of containers are used to collect and store classified refuse: combustible and noncombustible residential refuse, combustible and noncombustible business refuse, and recycled refuse.

The refuse is delivered as follows: When the operator of a container car presses a delivery request button for a specific type of container, the requested container is automatically carried out to a container truck waiting area and delivered to the respective refuse receiving place. An empty container is automatically carried in, as with the carrying-out operation.

2.5 System operation control

The new features of the Yebisu Garden Place control system are as follows:

(1) Refuse discharging operation

The rotational speed of the storage drum is controlled by an inverter to maintain the optimum value when the refuse is loaded or unloaded. This stabilizes the refuse suction pressure and increases the collection capacity to about 1.5 times that of a conventional system.

(2) Automatic control of air quantity

The air volume at the blower inlet is automatically changed to ensure that the air velocity is suitable for the refuse quality of the building from which the refuse is collected.

(3) Clogging prevention

If the suction pressure of a blower exceeds a specified value during refuse collection, the increased suction pressure is assumed to be due to clogging, and a valve to the atmosphere is automatically adjusted to change the pressure in the refuse transportation pipe

Photo 1 Refuse loading door

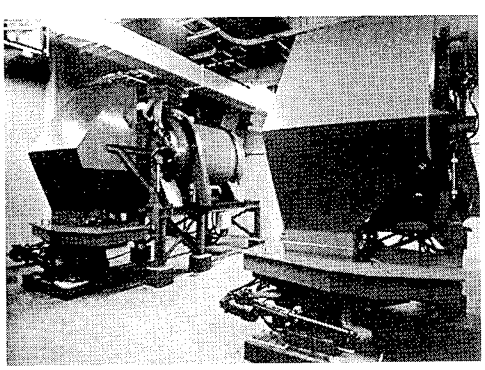


Photo 2 Storage and discharge unit

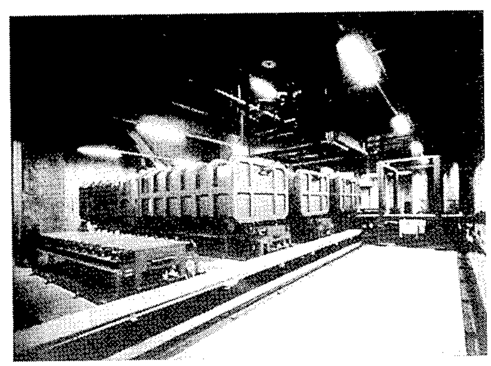


Photo 3 Container yard

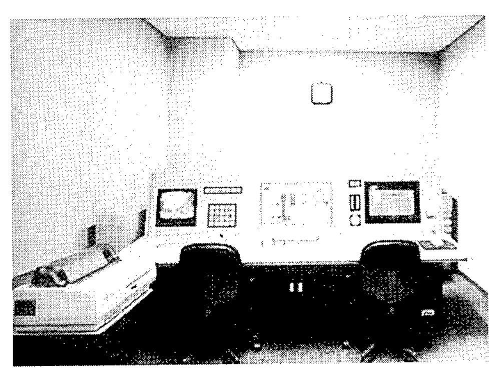


Photo 4 Central control unit

and prevent clogging.

(4) Refuse type switching operation

Five types of refuse are collected automatically in dedicated containers for each refuse type.

3. Pneumatic refuse transportation system problems and countermeasures

3.1 Problems with system

Pneumatic refuse transportation systems have a history of about 25 years since they were first introduced to Japan, and the plants have been appreciated by their users. At the same time, however, several problems have arisen, as described below.

(1) Conventional large-diameter plants, many of which have been built, primarily in new urban areas, require a large collection center site because of their large scale. The initial construction cost is also high. On the other hand, small-diameter plants equipped with a refuse crusher have been introduced in single buildings, but are unsuitable for a facility with many loading doors because the refuse crusher is relatively expensive.

Therefore, we developed a new pneumatic refuse transportation system that is expected to be introduced to medium-scale residential and existing urban areas in the future.

(2) At some plants, the refuse transportation pipe is worn by the refuse, decreasing its wall thickness and forming holes. Possible measures against wear include making the refuse transportation pipe straight, improving the pipe material, and reducing the transportation air velocity. The ability to straighten the pipe is limited because the piping layout is determined by tie-ins to road and building. Wear-resistant cast iron (bainitic cast iron, high chrome cast iron) and wear-resistant cast steel are now used as highly wear-resistant materials. However, these materials are expensive, which is one factor causing the initial construction cost to increase. Although reduced transportation air velocity is very effective in preventing wear, the possibility for reducing the transportation air velocity is limited because it depends on the refuse property and the transportation time.

(3) Recycling has been increasingly recognized since the Resource Recycling Law was put in force. Therefore, we must develop a new pneumatic collection system for resource recycling that meets present-day needs by enabling the promotion of recycling and efficient collection.

3.2 Measures against problems

For the pneumatic refuse transportation system to be appreciated widely and be developed as a desirable system, these problems must be solved. NKK is making efforts to develop such a system.

3.2.1 Medium-diameter plant

NKK designed a basic system for a medium-diameter plant for a medium-scale residence area or existing urban area after reviewing conventional systems. The basic concept of this system is to decrease the initial cost to 50% or less and the operating cost to 70% or less of a conventional large-diameter plant and to make the whole system small. The features of this system are as follows:

(1) The refuse transportation pipe diameter is changed from 500 to 600A to 350 to 400A.

(2) The loading door facility is simplified and modularized by increasing the number of collecting operations per day. It is also constructed to be buried directly to reduce the occupied area in the urban area.

(3) The equipment is made more compact so that the center can be housed in part of the underground parking area of a building or in the ground under public space.

At present, a pilot plant with a diameter of 350A was installed and proof tests are being made with the prospect of practical use. **Photo 5** shows the 350A pilot plant.

3.2.2 Measures against wear of refuse transportation pipe

Regarding wear-resistant material, NKK has already developed a wear-resistant, high silicon steel pipe that is approximately equal in workability and weldability to the JIS SS material, is low in cost, and has twice the wear resistance of SS400 material. This pipe was actually used as the refuse transportation pipe at Yebisu Garden Place.

Worn parts of refuse transportation pipe are repaired by welding a steel plate from outside the pipe. However, a new repair method needs to be developed to repair sections that are difficult to repair from the outside, such as buried sections. Also, when a worn portion of pipe is repaired by build-up welding from the inside, an automated welding operation is required to improve efficiency and the working environment. To meet these requirements, NKK started the development of an inside pipe welding robot, and the design and manufacture of a welding robot for 500 to 600 A pipe was completed. **Photo 6** shows the welding robot.

3.2.3 Bag collection system

NKK is developing a bag collection system for the pneumatic collection system for resource recycling, and it is already reaching the proof test stage. In this system, the refuse generator puts sorted refuse and resources in colored, special-purpose vinyl bags, which are given out in advance, and puts the bags into the loading door facility. One refuse storage discharge device is provided for each loading door facility at each location, where mixed colored bags are stored together. These bags are sequentially transported to the collection center through the pipeline at a speed such that the vinyl bag is not broken. The transported vinyl bags are separated from the air stream and stored using a separation discharge device and are then discharged sequentially to a selection line. On the selection line, the vinyl bag color is detected by an optical sensor, and the bag is discharged into hoppers by type. Combustible and noncombustible refuse are discharged and stored in containers using a compactor, and resources are discharged and stored in separate open containers. The containers are then conveyed to a treatment area.

The bag collection system is not only effective for performing recycling, but also for preventing wear and decreasing the operating cost by reducing the power of the blower because the bag system can transport the refuse with a lower air velocity than the conventional pneumatic refuse transportation system. **Photo 7** shows the equipment for color selection.

4. Concluding remarks

At present, the pneumatic refuse transportation system needs to be changed to a system that meets new social needs. To meet these new needs, NKK intends to carry out research and development to realize a more economical and rational system. Also, we plan to investigate refuse treatment methods for a new city and propose a better system in the future that is not limited to a pneumatic refuse transportation system by utilizing our know-how as a comprehensive, city development company.

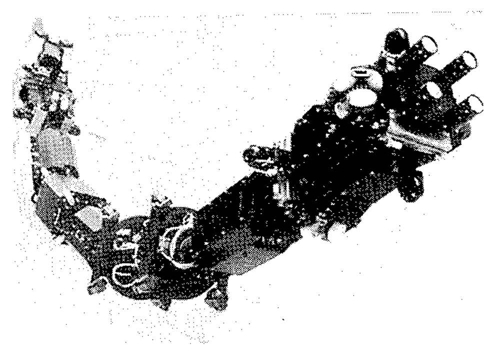


Photo 6 Welding robot

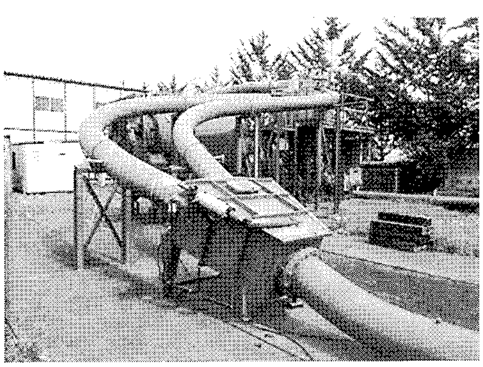


Photo 5 350A Pilot plant

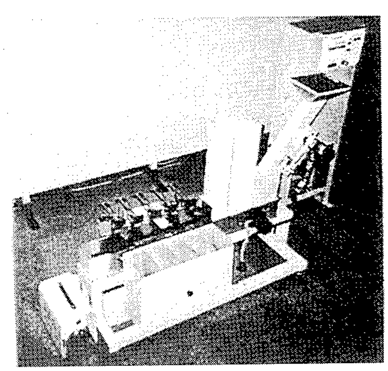


Photo 7 The equipment for color selection

Recycling of Waste Plastics in a Blast Furnace System

Kazumasa Wakimoto*, Hiromi Nakamura**,
Ysuhiro Fujii***, Yutaka Yamada****,
Kenichi Nemoto**** and Koichi Tomioka*****

NKK developed a new plastics recycling system. Waste plastics are injected into a blast furnace after lumpy plastics are pulverized by crushing and granulating, and film type plastics are agglomerated. The plastics are used as a substitute for coke in making iron. The system has an annual capacity of 30000 tons and has been operating since October 1996. The total recycling ratio of waste plastics reached as high as 76% (51% material recycling and 25% thermal recycling).

1. Introduction

Most of the waste plastics that are discarded in Japan are not reused, but are incinerated or used for landfill, as shown in **Fig. 1**. The disposal of waste plastics has become a serious social problem, considering both environmental conservation and the significant loss of resources and energy for Japan, which has limited resources.

In response, NKK developed an integrated waste

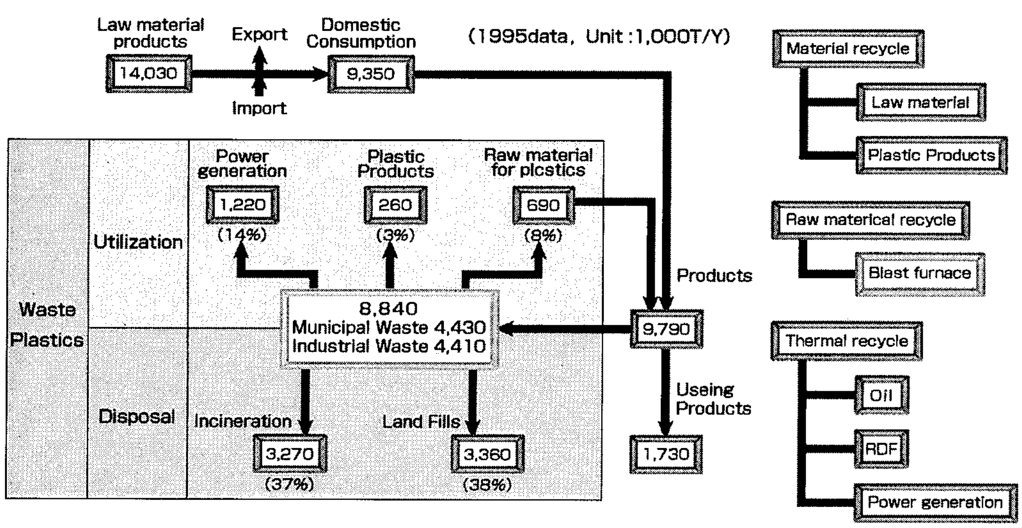


Fig. 1 Treatment of waste plastics in Japan

* General Manager, Keihin Works, Iron and Steel Making Dept.
** Superintendent, Keihin Works, Iron and Steel Making Dept.
*** Manager, Keihin Works, Waste Plastics Recycling Team
**** Team Leader, Keihin Works, Waste Plastics Recycling Team
***** Assistant Manager, Keihin Works, Waste Plastics Recycling Team

plastics recycling system. Collected waste plastics are classified, crushed, agglomerated, and then used as a raw material for iron making by injection into the Keihin No.1 Blast Furnace[1]. This furnace has an internal capacity of 4907 m^3 and started operation in November 1989.

The technology for charging waste plastics into a blast furnace was brought into practical application by Stahlwerke Bremen Gmbh. of Germany. The integrated waste plastics recycling system developed by NKK, however, is the first integrated recycling system in the world. The system has equipment for crushing and agglomerating waste plastics to prepare the raw material and for charging the material into blast furnace. The NKK recycling system began commercial operation in October 1996, and industrial waste plastics (except polyvinylchloride) are currently being recycled at an annual rate of 30000 tons (**Photo 1**).

2. NKK's challenge on environmental problems

For many years, NKK's management policy has been to contribute to society by performing global environmental protection and by establishing a society of resource recycling. Under this policy, NKK makes every effort, as a total corporate activity, to conserve resources, save energy, and protect the environment by integrating the iron and steel making technology and by developing engineering technology under various in-house promotional organizations, such as the Global Environmental Synergy Committee and the Environmental Recycling Promotion Conference.

Photo 1 Pretreatment facilities

As part of these activities, the Keihin Works pursues resource conservation, energy saving, and environmental protection in a metropolitan area by characterizing the Works as being compatible with urban life and harmonious with the environment, owing to its location near Tokyo Metropolis.

3. Blast furnace

The blast furnace, which is an upstream, iron works facility, is a reactor for producing molten iron from iron ore and coke (**Fig. 2**). The inside of a blast furnace is illustrated in **Fig. 3** as a vertical, cross-sectional view.

Iron ore and coal undergo preliminary treatment and are then alternately charged from the top of the blast furnace as sintered ore and coke. A hot blast of about 1200°C is blown into the blast furnace through tuyeres (**Photo 2**) at lower portion of the blast furnace to gasify the coke and pulverized coal that is charged through the tuyeres to generate CO. The hot CO gas reduces the sintered ore (FeO) to yield Fe and CO_2, while melting the generated iron. The molten iron and slag are discharged from tapping holes at the bottom of the blast furnace. The No. 1 blast furnace of Keihin Works produces 10000 tons of pig iron per day, using about 4000 tons of coke, 1000 tons of pulverized coal,

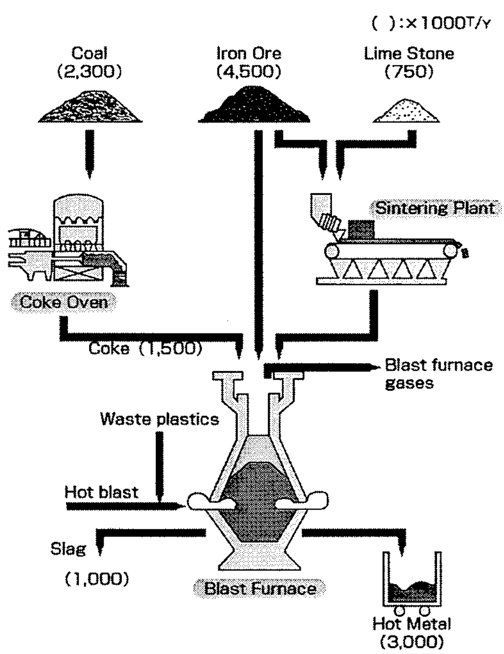


Fig.2 Material flow of iron making in the Keihin Works

and 16000 tons of iron ore.

4. Development

The NKK recycling system was developed as an elemental technology for the next-generation multipurpose scrap melting process[2)]. The study began in 1993. The system was brought into practical use after a commercial test operation at the No. 1 blast furnace of Keihin Works. In the blast furnace test, pre-processed waste plastics, which were crushed and agglomerated in advance, were stored in the dispenser tank shown in **Fig. 4**. The pre-processed waste plastics were transferred through a pneumatic pipeline using compressed air into the blast furnace through one of the forty tuyeres. The test included the injection of a total of 1000 tons of the pre-processed waste plastics. The injection method had already been established for charging pulverized coal into the blast furnace and was thus used for the blast furnace test. **Table 1** shows data

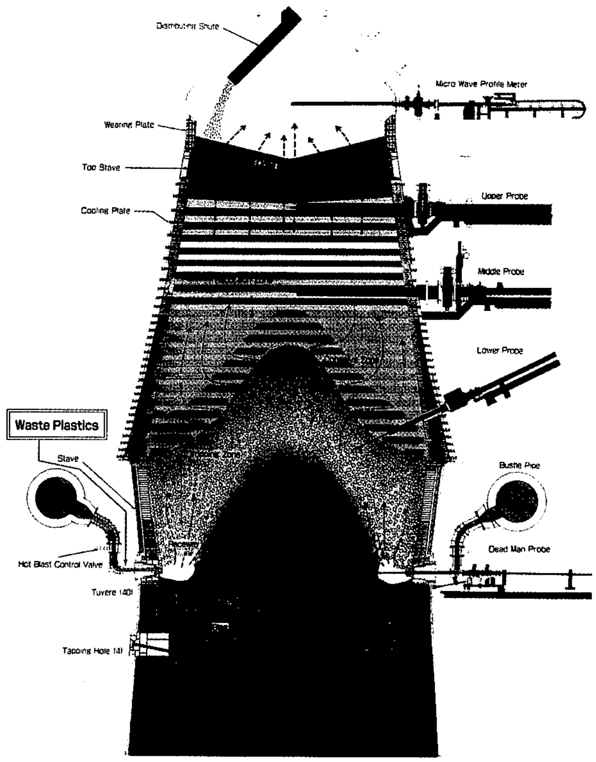


Fig. 3 Blast furnace process

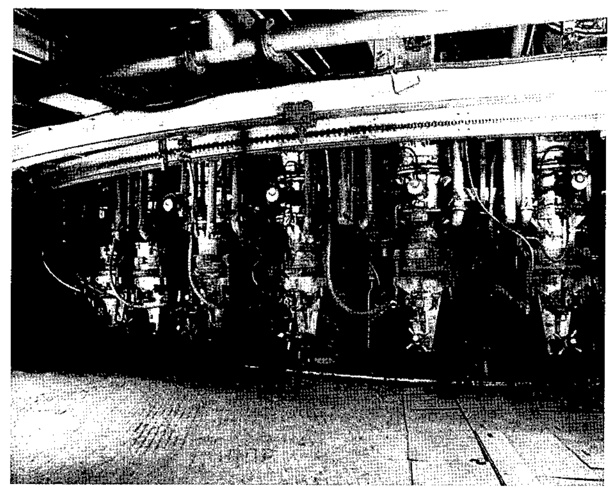


Photo 2 At a blast furnace tuyere

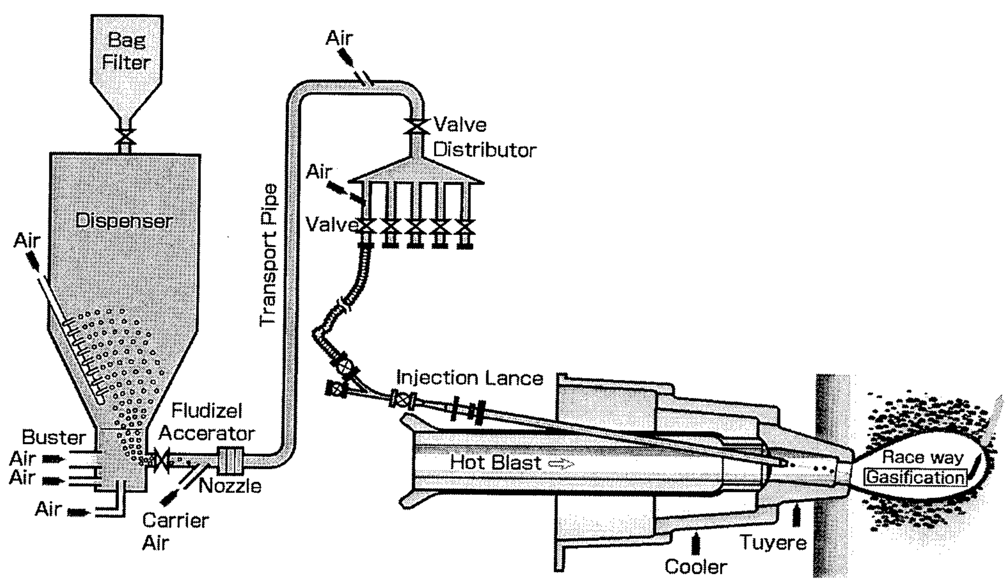


Fig. 4 Flow of test for waste plastics injection

before and after the charge test for the pre-processed waste plastics in the blast furnace. No operational problem occurred, and the data shows that charging the pre-processed waste plastics increases the amount and calorific value of generated gas.

The development of each elemental technology is described below.

4.1 Technology for crushing and agglomerating waste plastics

Waste plastics are largely grouped into lumpy solids and films. Lumpy solid waste plastics can be pre-processed by the combination of a conventional crusher and a pulverizer. However, simple crushing of filmy waste plastics was found to produce a fluff of plastics, which caused serious problems by fouling the dispenser tank and clogging the pneumatic transport pipeline. We tried various measures at site to solve this problem and found that melt-agglomeration is the optimum process for treating filmy waste plastics. The waste plastics are cut into pieces and agitated in a tank, which melts them by friction heat. This is followed by a water spray to rapidly cool and solidify the agglomerated plastic, and finally by pulverizing and agglomerating processes.

4.2 Transferring the pre-processed waste plastics

For pneumatic transfer of the pre-processed waste plastics, optimization of the solid/air weight ratio is critically important. If the solid/air ratio is large (high transportation rate), problems during transportation such as plugging of the transfer pipeline are likely to occur. On the other hand, reducing the solid/air ratio (low transportation ratio) increases the equipment and operation cost. When the particle size of the pre-processed waste plastics is reduced, transportation and gasification in the raceway become easy, but the pulverization and agglomeration cost increases.

There are many additional controlling variables, such as the pipeline size and air pressure, and these variables interact with each other. Accordingly, optimization of the design of operating conditions is important. The technology for optimizing these conditions has been established.

4.3 Gasification of pre-processed waste plastics at raceway[3)]

Photo 3 shows the state of gasified pre-processed waste plastics at the raceway compared to the state of pulverized coal injection. The maximum injection rate tested was 2.4 t/h per tuyere (or 200 kg per ton of pig

Table 1 Blast furnace operation for plastics injection

	Base Condition	Plastics Injection
Plastics Ratio (kg/t)	0	3
Pulverized coal ratio (kg/t)	72	73
Coke Rate (kg/t)	473	468
Fuel Rate (kg/t)	545	544
Hot Metal Production (t/D)	10,600	10,638
Hot Metal Temperature (°C)	1,520	1,518
CO (%) (in Blast Furnace Gas)	26.3	26.5
CO_2 (%)	21.5	21.3
H_2 (%)	3.4	3.7
Blast Furnace Gas Volume (Nm^3/t)	1,758	1,778
Gas Calorific Value (kJ/Nm^3)	3732	3757

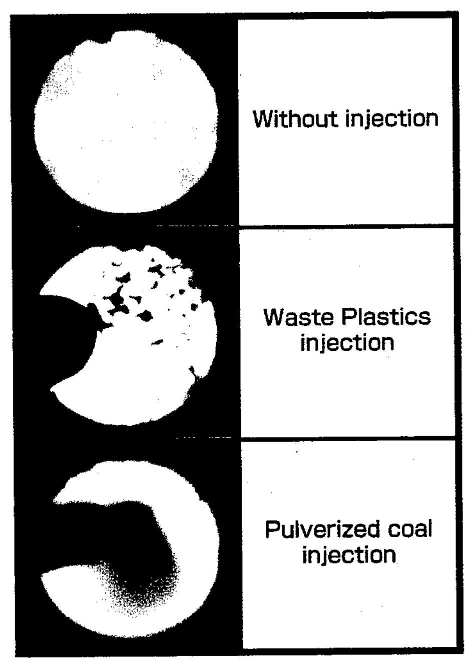


Photo 3 Condition of the raceway

iron, which is the maximum theoretical value), and no problem occurred in the raceway. As seen in **Photo 3**, the injected pre-processed waste plastics entered the blast furnace, while maintaining their particulate shape, and then were gasified in the raceway, which is at a high temperature of about 2400°C. The pre-processed waste plastics demonstrated a much greater gasification rate than that of the pulverized coal, even though the particle size of the pre-processed waste plastics was 20- 30 times that of the pulverized coal.

5. Waste plastic recycling system in blast furnace

We designed the NKK recycling system based on the results of the blast furnace tests described above. This integrated recycling system, which covers the range from waste plastics collection, crushing, and agglomeration, to injection into blast furnace, was brought into commercial application (**Fig. 5**).

The collected waste plastics are classified by shape as either lumpy solids or films. The classified waste plastics are crushed and agglomerated, and then held in a storage silo as pre-processed waste plastics. The pre-processed waste plastics are transferred to the dispenser tank before being charged into the blast furnace. The pre-processed waste plastics are pneumatically transferred from the dispenser tank by compressed air for injection into the hot blast through four of the forty tuyeres. The injected pre-processed waste plastics are immediately converted into reducing gases (CO, H_2) in accordance with the reactions shown in **Fig. 6**. This reduces the iron ore (iron oxide), which ascends in the blast furnace, and heats and melts the ore. This function is similar to the reducing function of coke and pulverized coal. Therefore, the waste plastics provide a substitute for coke and pulverized coal.

The gases that were used for reduction and heating in the blast furnace are vented from top of the furnace. These gases, which are called "B" gas and have a calorific value of about 3,350 kJ/Nm³, are supplied to in-house power plant and heating furnaces as a fuel.

Fig. 7 shows the utilization ratio of reduction gases generated from the waste plastics and the energy utilization ratio in the NKK recycling system. The utilization ratio for reduction exceeds 50%, which indicates that the pre-processed waste plastics are satisfactorily recycled as a material. (In Germany, the recycling of waste plastics is officially accepted as a material recycling process.) At the bottom portion in a blast furnace, heat exchange occurs between the reduction gas of 2400°C and sintered ore (FeO). As a result of the heat exchange, temperature of the gas becomes 150C

Gas reaction of the waste plastics in the tuyere head

$$C\ (\text{plastics}) + CO_2 = 2CO$$

$$2H\ (\text{plastics}) = H_2$$

Reduction of the iron ore in the blast furnace

$$FeO_x + X\ CO = Fe + X\ CO_2$$

$$FeO_x + X\ H_2 = Fe + X\ H_2O$$

Fig. 6 Reaction in the blast furnace

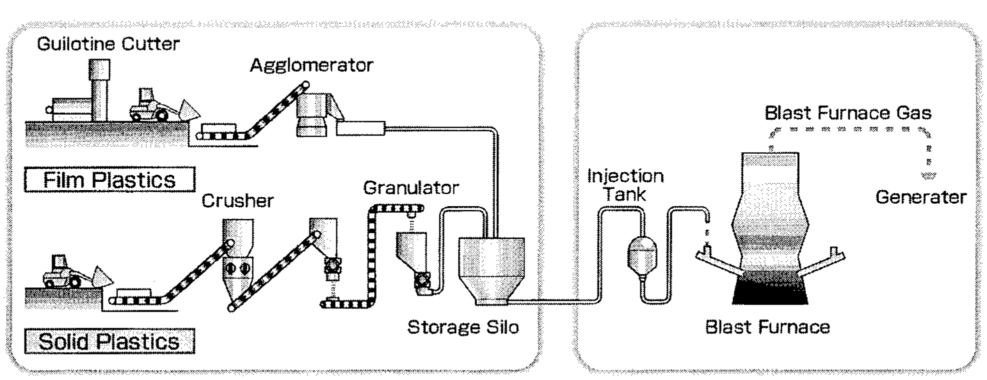


Fig. 5 Waste plastics recycling system combined with blast furnace

at the top of the furnace, so the heat efficiency is as high as 90% or more. As a result, the energy utilization ratio of the pre-processed waste plastics is 80% or more as a total system within an iron works, making this a high efficiency recycling process that has no parallel in industry[4].

Accordingly, this recycling process is superior to others in terms of resource conservation and energy saving. The energy saving effect decreases CO_2 emissions, and also the substitution of hydrocarbon plastics for coal coke decreases CO_2 generation in the iron-making process.

6. Present state of recycling

During the period between October 1996 to early 1997 when NKK was launching the NKK recycling system, many companies hesitated to adopt this system for financial reasons, although they recognized the technological advantages of waste plastics recycling. Recently, however, an increasing number of companies have adopted the policy of "truly friendly to the global environment," even when the cost increases to some extent, in response to the ever-increasing concern about global environmental conservation. NKK recycling system is widely accepted in those companies since they aim at the acquisition of ISO-14001 endorsement.

After negotiations with several hundred companies in the fields of electrical, communication, automotive, machinery, chemicals, printing, film, plastics processing, and supermarkets, NKK entered agreements with a number of firms for the collection of waste plastics and the preparation of pre-processed waste plastics. Typical waste plastics include OA equipment, bottles and containers, magnetic tapes, and film sheets.

7. Issues

7.1 Polyvinylchloride (PVC)

When PVC is treated in the NKK recycling system, acid corrosion of the blast furnace facilities may occur due to chlorine in the PVC. To cope with this problem, NKK is developing gravity separation technology, to separate PVC from other plastics, and high performance chlorine removal technology, to separate chlorine from PVC. Through these technologies, PVC will be completely treated in the NKK recycling system in the near future.

7.2 Waste plastics in municipal solid waste

Government and ministerial ordinances on the Packaging Waste Recycling Law were issued in December 1995 and were extended to apply to PET bottles in April 1997. To this point, the NKK recycling system uses the material as a raw material for blast furnace. Therefore, the establishment of this PVC treatment technology should satisfactorily respond to the Law. Furthermore, the NKK recycling system should contribute to the achievement of a large mass recycling system (**Fig. 8**).

In this respect, NKK received a consignment work order for "Research of a model for municipal waste plastics recycling in a blast furnace system" from the

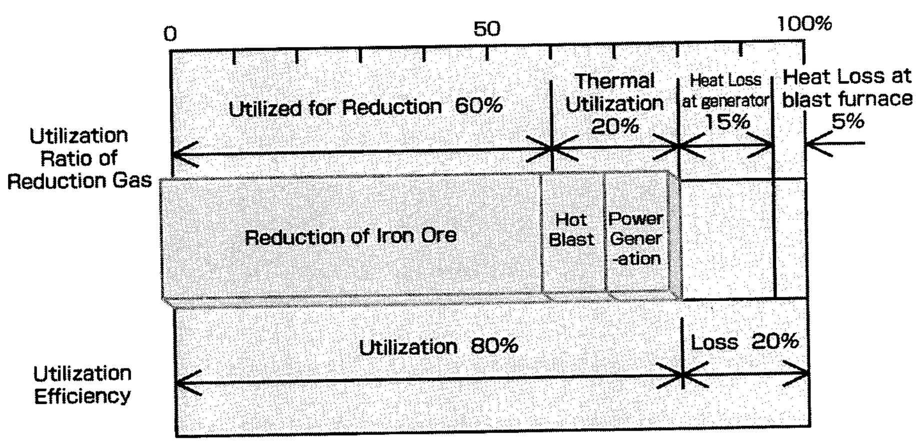


Fig. 7 Utilization efficiency of waste plastics for blast furnace system

Ministry of International Trade and Industry in fiscal 1996. Thus, NKK studied the recycling of waste plastics bottles in the blast furnace jointly with the Iron and Steel Institute of Japan and the Japan Chemical Industry Association. This work confirmed that no operational problems occur (**Photo 4**).

In addition, during fiscal 1997, NKK operated a national project led by the Ministry of International Trade and Industry to develop shape classification of plastics and the separation of PVC in municipal solid waste.

8. Conclusion

The NKK recycling system recycles waste plastics, which are conventionally incinerated or dumped in landfill without reuse, as a raw material for the blast furnace.

Features of NKK recycling system are the following.

(1) The system reduces the volume of dumped plastics waste.
(2) The system eliminates the need for landfill sites for plastics waste.
(3) The system decreases coke consumption, which saves coal resources that fully depend on imports.
(4) The system decreases the emissions of carbon dioxide, thus contributing to measures against global warming.
(5) The system does not generate toxic by-product gases, and the less toxic by-product gases are reusable in existing plants for power generation, etc.
(6) The system offers 80% or more total energy efficiency in the blast furnace, so the system is superior to other recycling processes in terms of resource and energy conservation.

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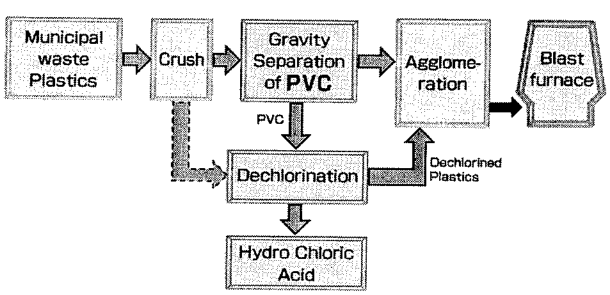

Fig. 8 Treatment of PVC

Photo 4 Waste plastics bottle before shearing

Advanced Biological Water Treatment Using Immobilization Technology

Toshiaki Tsubone*, Kei Baba**,
Toyoshi Sawada**, Hideki Yamada**,
Tatsuo Takechi*** and Hiroshi Atsuura****

NKK developed new advanced biological waste water treatment systems that incorporate immobilization technology. This paper reports the development of our carrier for microorganism immobilization and summarizes the characteristics of some newly-developed waste water treatment systems, including nitrogen and phosphorus removal systems, that use the carrier technology.

1. Introduction

Present and future issues on waste water treatment technology include the improvement of treated water quality, the reduction of energy used during treatment, and the reduction of area occupied by the treatment facilities. The Ministry of Construction conducted a comprehensive technology development project ("Bio-Focus WT") between FY' 85 to FY' 89 to develop new, sophisticated waste water treatment methods. Different waste water treatment systems that use single or combined immobilization carriers were developed in this project.

Fluidized bed bioreactors use carriers to immobilize microorganisms that contribute to waste water treatment. The microorganisms are immobilized onto the surfaces of or within the carriers, and the carriers can then be circulated within an aeration tank to further facilitate waste water treatment. This technology has recently attracted attention in the industry because the carriers maintain high concentrations of microorganisms within the aeration tank, and can thereby reduce the size of the aeration tank and improve the quality of treated water.

Through the Bio-Focus project development, NKK developed a fluidized bed bioreactor that uses cylindrically -shaped, polypropylene carriers. This paper describes the selection and development of the microorganism immobilization carrier used in the fluidized bed bioreactor. Applications of the developed bioreactor technologies in various waste water treatment systems are described, along with characteristics of the application systems.

2. Selection and development of the microorganism immobilization carrier

Methods for immobilizing microorganisms using a carrier can be roughly classified into the entrapment method and the binding method.

In the entrapment method, large quantities of microorganisms are immobilized within the lattices of

* Senior Research Engineer, Dr. Aqua Systems Lab, Kawasaki Research Center
** Aqua Systems Lab, Kawasaki Research Center
*** Manager, Dr. Aqua Systems Lab, Kawasaki Research Center
**** Manager, Plant Technology Team, Water Treatment Plant Engineering Dept.

polymer gels (as a carrier) by mixing microorganisms with a water-soluble polymer, such as polyethylene glycol or polyvinyl alcohol, and then polymerizing to gel the water-soluble polymer. Probable advantages of this method are that the microorganisms are immobilized in high concentrations, the preferential use of one specific species of microorganism is possible for removal of a specific organic substances, and the volume of sludge generated is reduced.

In the binding method, microorganisms are immobilized by using the viscous materials that the microorganisms produce to provide spontaneous adhesion to the surface of carrier particles such as sand, activated carbon, or plastic beads, and by forming a biofilm of microorganisms over the surface.

To select a carrier type, NKK conducted studies on both methods. The entrapment method has generally been thought to permit a high concentration of microorganisms to be immobilized inside of the carrier. However, a biofilm can be formed on the external surface of the carrier during waste water treatment, which decreases diffusion of the substrate and oxygen. As a result, the effective layer may be reduced to only the external surface area of the biofilm on the carrier. In this condition, no merits are obtained from the immobilization of microorganisms inside the carrier. Moreover, the disadvantages are more pronounced because the space inside the carriers is not used, decreasing the effective capacity of the reactor.

To identify whether this phenomenon occurs, we fabricated spherical carriers both with and without microorganisms entrapped inside for two carrier materials: a photopolymerizable resin consisting mainly of polyethylene glycol and a resin consisting mainly of polyvinyl alcohol. We conducted a series of experiments with the continuous treatment of waste water by using each type of carrier in a fluidized bed[1]. For both carrier materials, there appeared to be very little difference between the presence and absence of microorganisms immobilized inside in the respiration rate and the dissolved biological oxygen demand (BOD) of the treated water. **Photo 1** is an SEM image showing the cross section of a carrier (made from a photopolymerizable resin consisting mainly of polyethylene glycol) with the microorganisms immobilized by entrapping them inside after use for three months of continuous waste water treatment. As seen in the photograph, the presence of microorganisms was limited to the surface area of the carrier.

These findings suggest that immobilization of microorganisms inside a carrier has no effect, at least on the removal of biological oxygen demand (BOD) substances. In addition, Matsubara, et al. conducted a waste water treatment experiment using carriers for entrapping nitrifiers that were prepared by freezing polyvinyl alcohol. They also found that the immobilization of nitrifiers by trapping inside does not provide a significant effect on the nitrification of waste water. We therefore focused on the development of a binding type carrier. This type is more economical because the carrier material can be obtained at low cost and provides good wear resistance.

Characteristics required for a binding type carrier for a fluidized bed bioreactor include the following.

(1) Good adhesiveness with microorganisms
(2) Good mobility
(3) Long service life
(4) Low cost

After various kinds of materials were investigated for an effective carrier, NKK developed the hollow resin carrier shown in **Photo 2**.

The carrier is treated to make its surface rough to enhance the adherence of microorganisms. It has a cylindrical hollow shape (4 mm outside diameter, 3 mm inside diameter, and 5 mm long) to increase the amount of attached microorganisms per unit volume. The matrix is made of polypropylene, and the carrier is adjusted to have a specific gravity slightly heavier than

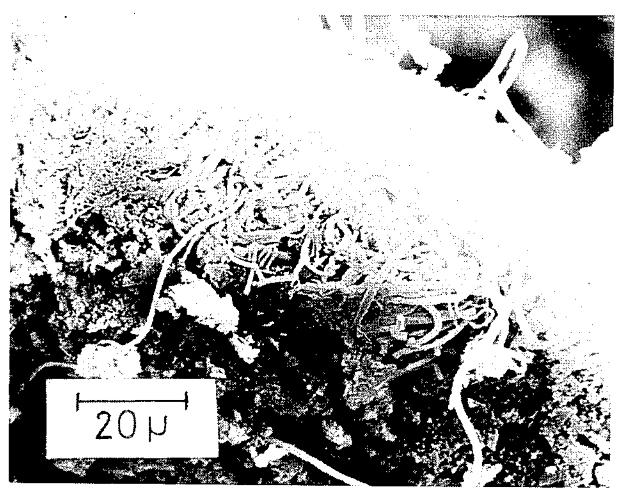

Photo 1 Cross section of the carrier prepared by entrapment method

that of water. Because the difference in specific gravity between the carrier and water is very slight, the carrier has excellent mobility in water. Consequently, an aeration method that uses the whole floor of the tank for aeration and therefore needs much less energy for agitation of the carriers can be used for the carrier, thus a high oxygen transfer rate is attained with less energy consumption. Another advantage of the carrier is that polypropylene has high resistance to chemical and biological degradation and high mechanical strength, so the carrier withstands long periods of service. Furthermore, polypropylene is an inexpensive resin, so that the carrier is prepared at low cost. Lastly, a wide range of sizes and shapes are available for the carrier by selecting molding conditions.

3. Applications of the fluidized bed bioreactor

Various application systems are proposed for the hollow resin carrier fluidized bed bioreactor system. We conducted many experiments and studies for different application systems, including the pilot plant tests under the Bio-Focus Project, and published the results[1)-5)]. Some representative application examples are outlined below.

(Application - 1)

The system shown in **Fig. 1** consists of an aeration tank that contains carriers, and a solid-liquid separator for the following step. The principle of operation is as follows: influent from primary sedimentation basin enters an aeration tank (fluidized bed bioreactor), where the water is biochemically treated by microorganisms attached to the carriers. The water is then fed into the solid-liquid separator in the next step, where suspended solids (SS) in the water are removed to finally produce clear, treated water. The aeration tank is normally divided into at least three sections by a wedge-wired screen to prevent the carriers from concentrating downstream and to form three different microorganism phases from the upstream side to the downstream side of the tank. A wedge-wired screen is located between the separated sections and at the exit of the aeration tank to prevent the carriers from flowing out.

The aeration tank mainly provides decomposition and the removal of dissolved organic substances, but removes very little SS. Water that has been treated in the aeration tank contains microorganisms that have grown on the carriers and then separated from them. Therefore, solid-liquid separation is required to remove such SS. This system incorporates a solid-liquid separator in the next step after the tank to remove SS materials from the water treated by the aeration tank to produce clear treated water.

Various types of solid-liquid separators are available for this system, and we evaluated two types: a down-flow multimedia filter and an up-flow sand filter. The down-flow multimedia filter used nonwoven fabrics, anthracite, and sand. The up-flow sand filter contained sand layers in gradually decreasing particle size from bottom to top, to increase the amount of captured SS per unit area of filter base over that obtained in a conventional up-flow sand filter.

Since this type of fluidized bed bioreactor system can hold a high concentration of microorganisms within the aeration tank, the size of the aeration tank can be decreased. An additional advantage of the system is that

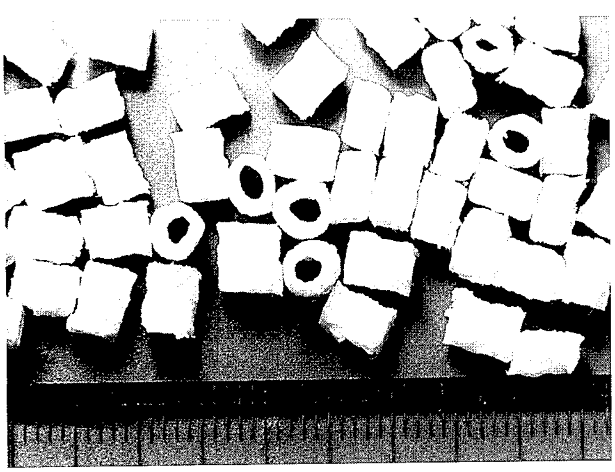

Photo 2 NKK-developed cylindrical carrier used for immobilization of microorganisms

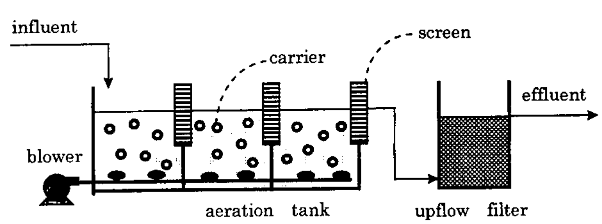

Fig. 1 Flow diagram of BOD removal system (I)

it is free from bulking problems, often encountered with the conventional activated sludge process, because this system does not perform sedimentation separation of activated sludge in the final sedimentation basin for recycling sedimented sludge. Furthermore, the formation of a microorganism phase suitable for the quality and quantity of the waste water in each section of the aeration tank was confirmed, adding effectiveness to the treatment method.

An experimental study was performed to evaluate the validity of employing an up-flow sand filtration, solid-liquid separator system for the step after the aeration tank, for the new waste water treatment facilities at Miyakonojo City of Miyazaki Prefecture. The results indicated that this system is more advantageous because the quality of treated water is more favorable than that from the standard activated sludge process, the area occupied by the facilities is less, and the rate of energy generation is higher. Although the net facility cost is somewhat high, the investment cost is nearly equal after taking into account the cost of land saved as a result of the decreased area.

Because the evaluation results were favorable, a commercial plant using this system was constructed at Miyakonojo City. The plant has been in operation since May 1996. Satisfactory performance was demonstrated, with the average value of BOD and SS at 2.8 mg/l and 1.1 mg/l, respectively, during the initial period of the plant operation. The conditions were 10 % net packing density of the carrier in the aeration tank and an inflow rate of about 16% of the designed level. The carrier mobility is favorable in the current commercial operation, and the carriers are almost uniformly distributed over the whole area of the aeration tank.

The conventional activated sludge process aeration tank can not hold a high concentration of nitrifiers and bacteria because they are difficult to hold in the conventional tank due to their slow growth rates. However, this system can hold nitrifiers and bacteria such as microbes that break down refractory organic substances at a high concentration in the aeration tank by immobilizing them onto the carriers. This feature of the system is demonstrated by the system's high nitrification rate and high removal rate of refractory COD substances as has been previously reported.

Many existing waste water treatment plants use a conventional activated sludge process. However, some facilities need to cope with an ever-increasing load that exceeds the designed level within the limited land area and require a system that increases capacity just by modifying the facility. The technologies in this system can satisfy the demand for increased capacity in such existing facilities by modifications such as providing carriers in the aeration tank, installing wedge-wired screens to separate carriers, and changing the final sedimentation basin to a filter basin.

(Application - 2)

The system shown in **Fig. 2** charges carriers into an activated sludge process aeration tank and uses wedge-wired screens for separating the carriers in the tank. This system was employed in the plant in Takanezawa Cho, Tochigi Prefecture, and presents an example of the modification of an existing facility. The facility had a maximum throughput of 600 m^3/d. However, the modified plant with a combination of long-term aeration and a packed bed reactor, which began operation in March 1993, increased the maximum throughput to 2100 m^3/d. The carrier packing density is 5 % and the hydraulic retention time in the aeration tank is 4.6 hours to provide water with 4 mg/l of T-BOD and 2 mg/l of SS after treatment. This satisfied the target value of 5 mg/l of T-BOD and 20 mg/l of SS.

(Applications - 3, 4)

The pre-denitrification-nitrification system removes nitrogen from the influent by nitrifying ammonia nitrogen into nitrate nitrogen in a downstream nitrification tank, and then returning part of the formed nitrate nitrogen to the preceding denitrification tank, where the nitrate nitrogen is reduced into nitrogen gas by denitrifying bacteria.

On the other hand, the anaerobic-anoxic-aerobic system not only removes the nitrogen using the same

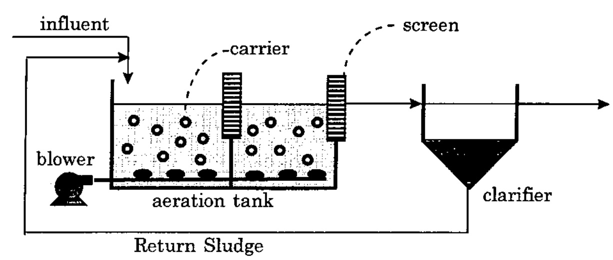

Fig. 2 Flow diagram of BOD removal system (II)

principle as the pre-denitrification-nitrification system, but also removes phosphorus from the influent. Phosphorous is removed by making the activated sludge release phosphorus in the anaerobic tank and then making the activated sludge absorb more phosphorus than that released in the aerobic tank. Increasing the concentration of phosphorus in the sludge increases the amount of phosphorus discharged.

Both systems aim to provide high grade treatment of waste water. However, these systems require a larger reactor — about twice the capacity of that used for the conventional activated sludge process to treat the same amount of water— because these systems need about 16 hours of hydraulic retention time in the reactor compared to 6 to 8 hours for the conventional activated sludge process. Thus, the systems shown in **Figs. 3** and **4** were developed as a modified nitrogen removal system and a modified anaerobic-anoxic-aerobic system, respectively, where carriers are charged into the aeration tanks (aerobic tank). These systems aim to decrease the size of the reactor and stabilize nitrification by maintaining a high concentration of nitrifiers in the aeration tank using the carriers.

A series of experiments were conducted jointly with Kawasaki City by incorporating the systems shown in **Figs. 3** and **4** into a 15 m^3/d pilot plant. **Table 1** shows the quality of treated water using the system shown in **Fig. 4** under the conditions of: 9 hours of hydraulic retention time, a ratio of recycle sludge to influent of 2.0, a ratio of return sludge to influent of 0.3, 1750 mg/l of mixed liquor suspended solids (MLSS), and a carrier packing density of 5%. The results were 7.8 mg/l of T-N in the treated water, which satisfied the target value of 10 mg/l or less.

On the other hand, the T-P of the treated water was 1.0 mg/l, which was a little higher than the target level of 0.5 mg/l. The reason for this probably comes from the small T-BOD/T-P ratio of the influent. **Fig. 5** shows the relation between T-P removal and the T-BOD/T-P ratio of the influent observed during the same experiment. The figure shows that they are proportional and that larger T-BOD/T-P ratios for the influent result in larger T-P removal ratios. This can be explained by the following. (1) This system removes phosphorus from the influent by concentrating phosphorus into the sludge, and then discharging the sludge as excess sludge. Thus, the more sludge is generated, the more phosphorus is removed. (2) The quantity of generated sludge (and excess sludge) is nearly proportional to the T-BOD concentration of the influent. Accordingly,

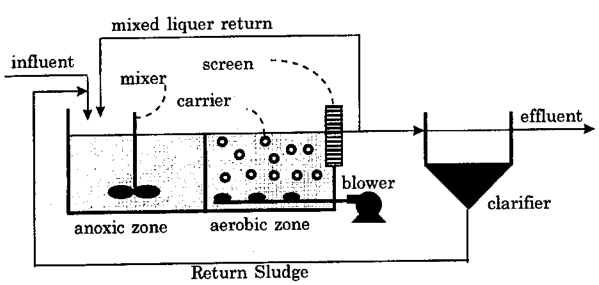

Fig. 3 Flow diagram of BOD and nitrogen removal system (I)

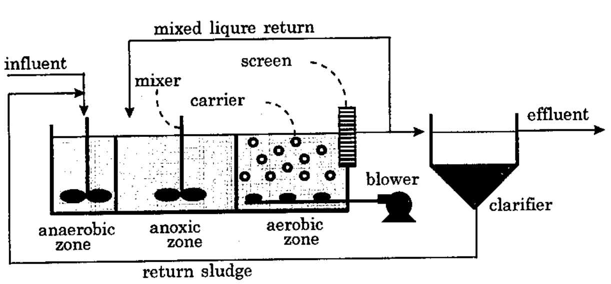

Fig. 4 Flow diagram of BOD, nitrogen and phosphorus removal system

Table 1 Average composition of influent and effluent

	influent	effluent
BOD mg/L	69.0	2.0
COD mg/L	45.4	7.5
SS mg/L	53.5	1.5
T-N mg/L	27.4	7.8
NH_4-N mg/L	15.9	trace
T-P mg/L	3.2	1.0
PO_4-P mg/L	1.7	1.0

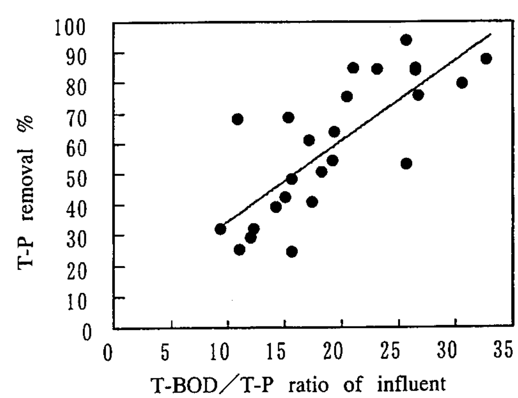

Fig. 5 Relation between T-P removal and T-BOD/T-P ratio of influent

the T-BOD concentration determines the T-P removal rate.

Generally, biological phosphorus removal should have a T-BOD/T-P ratio of 20 to 25 or more. However, 60% or more of the data acquired from this plant during the experiment had a T-BOD/T-P ratio of 25 or less. An effective method to compensate for the inadequate capacity of biological phosphorus removal caused by an insufficient T-BOD/T-P ratio in the influent should be to chemically solidify the phosphorus by adding a coagulant into the reactor, and then discharge the phosphorus as excess sludge. Poly-aluminum chloride (PAC) was used as the coagulant and added at an Al/P ratio of 1.5 or more, resulting in 0.5 mg/l of T-P in the treated water.

Nitrifiers in the sludge adhering to carriers and in the suspended sludge were counted during the experiment. At least 70% of the nitrosomonas (nitrous bacteria) and 90% or more of the nitrifiers (nitric bacteria) are immobilized onto the carrier surface in the reactor. Accordingly, the use of carriers was verified as being effective in maintaining a high concentration of nitrifiers within the reactor. A pilot plant experiment was performed using the pre-denitrification-nitrification system with carriers in the aerobic tank as shown in **Fig. 3**. The following findings were also observed in this experiment: dissolved BOD substances are easier to use as the reducing agent for denitrification than insoluble BOD substances, and the use of carriers is effective, not only for nitrogen removal, but also for BOD removal, with the effect being the most pronounced under heavy loading conditions.

Both the pre-denitrification-nitrification system and the anaerobic-anoxic-aerobic system need BOD substances as the hydrogen donor for denitrification. Some combination waste water treatment plants are, however, operated under a low BOD/T-N ratio, so that insufficient BOD substances are available for satisfactory denitrification. In this case, the primary sedimentation basin may be bypassed, or the sludge retention time in the primary sedimentation basin may be extended, to increase the BOD/T-N ratio in the influent. These kinds of measures, however, may increase the amount of foreign materials coming into the reactor, and therefore measures to remove foreign matters, such as modifying the reactor structure, are then required.

(Application - 5)

The system shown in **Fig. 6** is basically similar to that of **Fig. 3** — the pre-denitrification-nitrification system where carriers are charged into the aerobic tank. However, the system is different in that the carriers are charged only to the last two downstream stages of the aerobic tank, and no carriers are charged into the uppermost stream stage of the aerobic tank. The system is in the experimental stage in a joint study with Otsu City and is being used experimentally in a commercial line of the Otsu waste water treatment plant by modifying part of the activated sludge facilities. The reactor at the Otsu waste water treatment plant is called a "deep aeration tank reactor" and has diffusers in about the middle of the water depth, as illustrated in **Fig. 7**. The experimental conditions were: 11800 m^3/d of influent, 10200 m^3/d of recycle sludge, 7200 m^3/d of return sludge, 43000 m^3/d of air charge, 5.2 hours of hydraulic retention time. The carrier packing density was 2.5% until December 8, 1996, after which it was 3%.

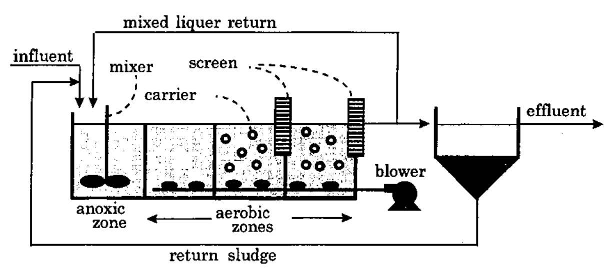

Fig. 6 Flow diagram of BOD and nitrogen removal system (II)

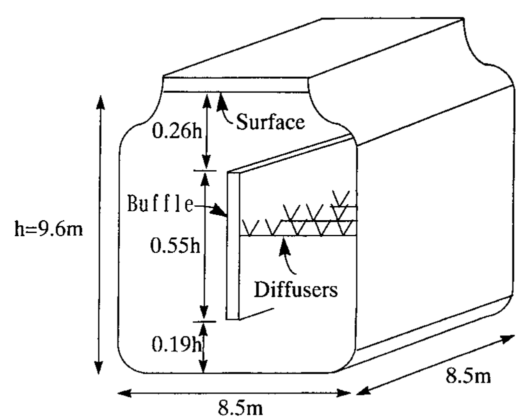

Fig. 7 Configuration of deep aeration tank system

Fig. 8 shows the change of water quality with time during the experiment. During a steady state operation period after the completion of sludge adhesion onto the carriers (March 14, 1996 to the end of March 1997), the average values of T-BOD and T-N in the treated water were 2.3 mg/l and 5.7 mg/l, respectively. The values consistently satisfied the target level of 10 mg/l or less of T-BOD and 10 mg/l or less of T-N. It was reported that charging entrapment immobilization carriers into a deep aeration tank reactor would need a basic modification of the reactor configuration because of the low mobility of the carriers. However, our experiment showed good mobility of the carriers, as demonstrated by the fact that they were distributed almost uniformly throughout the reactor, even though no basic modification of the reactor was made.

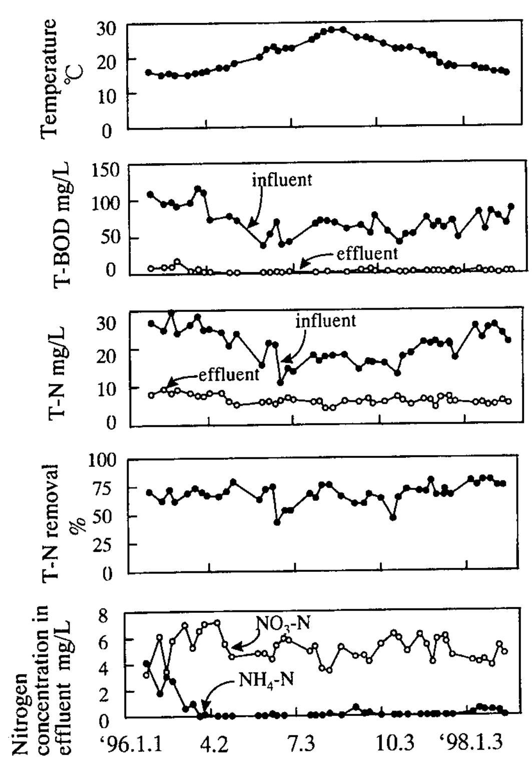

Fig. 8 Performance of BOD and nitrogen removal system (II) that uses deep aeration tanks

4. Conclusion

The paper outlines waste water treatment systems that use hollow resin carriers and describes the selection and development of the carrier and the application of the systems to waste water treatment facilities. All of these systems allow the treatment facility size to be reduced by utilizing carriers that immobilize a high concentration of microorganisms. Therefore, these systems are desirable, especially in areas where a sufficient treatment site is difficult to obtain. The installation of the system can then lead to more effective use of the land saved, such as for green zone. In addition, these systems are economically effective because they accommodate increased loads and higher grade treatments just by modifying existing treatment facilities.

In October 1998, a general discharge regulation of 60 mg/l of T-N and 8 mg/l of T-P will be enforced as a maritime countermeasure to eutrophication. Stricter regulations are sure to be enforced further in the future at many districts. We hope that the technologies introduced here will contribute to the improvement of water quality and conservation of the water environment in the future.

We would like to express our appreciation to emeritus professor Yasushi Kurihara of Tohoku University, professor Ryuichi Sudo of Tohoku University, project staff at the Public Works Research Institute of the Ministry of Construction, Japan Sewage Works Agency, Miyakonojo City, Takanezawa Cho of Tochigi Prefecture, Kawasaki City, Otsu City, and Nihon Suido Consultant for their guidance, advice, and cooperation in the series of research and development works.

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Drinking Water Treatment Using Micro-filtration Membrane

Tatsuo Takechi*, Torataro Minegishi**,
Shohei Fukada**, Masayuki Ikeda***
and Yoshihide Kageyama***

A series of pilot plant study on advanced drinking water treatment, including unit processes of biological filtration, membrane filtration, ozonation, activated carbon treatment and chlorine dioxide treatment, was conducted from September 1991 to March 1996, under a cooperation with Waterworks Bureau of Yokosuka City and NKK. This paper describes some operational characteristics, pollutant removal performances and cost analysis of microfiltration (MF) hollow fiber membrane.

1. Introduction

In recent years, technology for waterworks membrane filtration has been increasingly anticipated as a new drinking water treatment process that will continue into the 21st century. The Ministry of Health and Welfare started a demonstration project for the "research and development of a membrane separation technology for water treatment," called the MAC 21 Project (Membrane Aqua Century 21) in the fiscal year of 1991. This was initiated as a national project for applying membrane filtration technology to the small-scale drinking water treatment process[1)-2)]. In November 1994, the "Guideline on application of a membrane system to small-scale public water treatment" was published based on the results of the demonstration project. At present, membrane filtration technology is being used even at waterworks that handle over 1000 m^3 of water per day. Following the "MAC 21 Project," the Ministry of Health and Welfare organized the "research project for membrane separation technology for advanced water treatment" (Advanced Treatment MAC 21 project) as a three-year project starting in fiscal 1994 to develop a system for removing precursors of disinfecting by-products, offensive tastes and odor, etc., that are not expected to be removed completely by only ordinary membrane filtration, and a technique for sludge concentration using membrane filtration.

Prior to the "MAC 21 Project," the Waterworks Bureau of Yokosuka City and NKK started the "Technical Research Committee of Yokosuka City for New Drinking Water Treatment Process" to consistently supply safe and tasty water, and a pilot experiment and study on the "Next-generation advanced drinking water treatment process" in September 1991[3)-15)]. The object of this study is to comprehensively establish the next-generation water treatment process technology through pilot experiments that emphasize membrane filtration technology. The study evaluated the operation and treatment characteristics of biological filtration, ozonation plus activated carbon treatment, chlorine dioxide treatment, and a U-tube ozone contactor, which is an energy-saving and space-

* Manager, Dr., Aqua Technology Lab, Kawasaki Research Center
** Senior Research Engineer, Aqua Technology Lab, Kawasaki Research Center
*** Section Manager, Plant Technology Team, Water Treatment Plant Engineering Dept.

saving ozone contactor.

This paper describes the results of a study on an organic microfiltration (MF) membrane, which was one of the pilot experiments in the "Next-generation advanced drinking water treatment process" project that was carried out between September 1991 and March 1996.

2. Experimental method

2.1 Experimental flow

The experimental apparatus was installed at the Arima Waterworks of Yokosuka City, and the raw feedwater was taken from the Sagami River. The organic membrane pilot experiment apparatus treated 30 m^3 of water per day. A flow diagram for the experiment is shown in **Fig. 1**.

2.2 Membrane module

Table 1 shows the characteristics and operational conditions for the organic membrane module used in the experiment. The membrane is polypropylene MF hollow fiber membrane (made by Memtec Japan Limited), with pore size of 0.2 μm. The water flow is an external pressure system in which water flows from the outside to the inside. The hollow fiber membrane is bundled within the casing for modularization. The membrane module has five small modules with a membrane area of 2 m^2 and a total membrane area of 10 m^2. The membrane was operated under a constant trans membrane pressure of 50 kPa. To maintain the filtration capacity, physical cleaning was performed at fixed intervals. Physical cleaning was performed using compressed air at about 600 kPa blown from the inside to the outside of the hollow fiber after the flow of raw water was shut off. Water flowing outside of the hollow fiber collected the separated pollutants for elimination outside of the system[16].

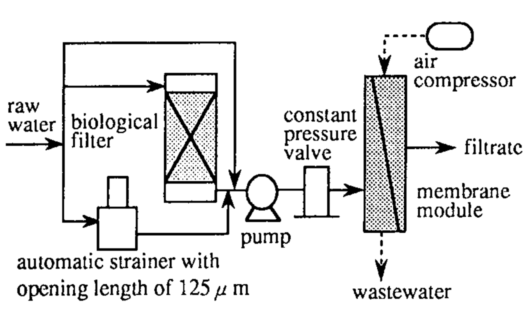

Fig. 1 Schematic flow diagram of the membrane plant

2.3 Experimental conditions

Table 2 shows the main operational conditions for the experimental period from fiscal 1991 to fiscal 1995. At the beginning of the experiment, cross-flow filtration was tested with a circulation percentage of 10% because the turbidity of raw water was very high (464 mg/l maximum) due to several typhoons. Subsequently, the operation mode was changed to dead end filtration, and the operation was continued. No coagulant was added during either period.

2.4 Analysis of water quality

The items that were analyzed in the membrane feed water and membrane filtrate included turbidity, color, pH, electrical conductivity, potassium permanganate consumption ($KMnO_4$ consumption), ammonia nitrogen, adsorption (260 nm), total organic carbon,

Table 1 Characteristics and operational conditions of the membrane

membrane	
pore size	0.2 μ m
material	polypropylene
type	hollow fiber
total area	10 m^2
operation	
inlet pressure	75 kPa
outlet pressure	25 kPa
physical washing by	compressed air and feed water

Table 2 Operational conditions of MF membrane plant

Run	Accumulated operational time hours	filtration mode	feed water for the membrane	IPW*2 min	coagulant addition
I	0- 870	cross-flow	effluent from the biological filter	15	no
II	870- 3200	dead-end	effluent from the biological filter	15	no
III	3200- 4370	dead-end	effluent from the biological filter	30	no
IV	4370-12000	dead-end	effluent from the biological filter	60	no
V	12000-13835	dead-end	Sagami River surface water	60	no
VI	13835-17030	dead-end	effluent from the biological filter	60	no
VII	17030-18875	dead-end	effluent from the AS*1(200 μ m)	60	no
VIII	18875-39900	dead-end	effluent from the AS*1(125 μ m)	30	no

*1 Automatic strainer *2 Interval of physical washing trihalomethane formation potential (THMFP), total Fe, total Mn, Al, soluble silicate, general bacteria, total coliform, and spore forming bacteria. Analyses were made once per day or once per month in accordance with Japanese Analysis Standard Method for Drinking Water. Samples for counting bacteria in the membrane filtrate were taken in a sealed vessel to prevent contact with air. Analysis of the water quality of the physical cleaning wastewater and chemical cleaning wastewater was made appropriately.

2.5 Chemical cleaning method

Until fiscal 1993, chemical cleaning was performed when the flux decreased to 50% of the initial flux just after chemical cleaning. However, starting in fiscal 1994, chemical cleaning was performed when the membrane filtration flux dropped to 0.5 m^3/day. For chemical cleaning, circulating operation and dip cleaning were performed using both a 2 wt % sodium hydroxide solution and a 1 wt % sulfuric acid solution.

3. Experimental results

3.1 Operational characteristics

3.1.1 Change in flux with time

Fig. 2 shows the change in membrane filtration flux (20°C viscosity converted value) with time for the period from September 1991 to March 1996 (accumulated operating time of 39,900 hours). The Run of I to VIII shown in **Fig. 2** corresponds to the experimental conditions shown in **Table 2**. The results shown in **Fig. 2** are summarized as follows:

(1) When effluent from the biological filter was used for membrane feed water, operation was relatively stable with a high flux that was not less than 2 $m^3/m^2/$day, without the addition of coagulant. The recovery percentage for only the membrane treatment portion reached an average of 95% when the physical cleaning interval was 60 minutes and the dead end filtration mode was used.

(2) For operation using surface river water or effluent from the automatic strainer (with opening length of 125 μ m) as the membrane feed water and without the addition of coagulant, the flux decreased to 50% of the initial flux when the physical cleaning interval was 60 minutes and the dead end filtration mode was used for 30 days. Even when the physical cleaning interval was 30 minutes, the flux decreased to about 50 % of the initial flux after about 75 days.

(3) A tendency for the flux to stabilize at about 0.7 m^3/m^2/day was found when the system was operated in the dead end filtration mode using effluent from the automatic strainer (with opening length of 125 μ m) treated water as membrane feed water with a physical cleaning interval of 30 minutes.

(4) If chemical cleaning was performed when the flux decreased to 0.5 m^3/m^2/day, the chemical cleaning frequency was two or less times per year.

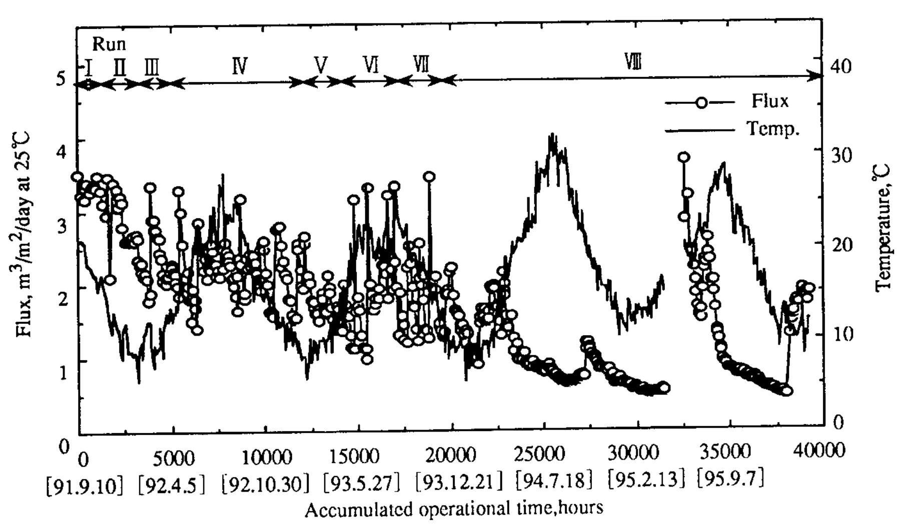

Fig. 2 Changes in temperature and flux of the membrane

3.1.2 Recovery of membrane filtration performance by chemical cleaning

Fig. 3 shows the change in membrane filtration flux (20°C viscosity converted value) with time just after chemical cleaning. The results shown in **Fig. 3** are summarized as follows:

(1) When chemical cleaning was performed after the flux decreased to 0.5 m^3/m^2/day, the membrane filtration flux just after chemical cleaning was about 3.8 m^3/m^2/day. This is nearly the same as the membrane filtration flux just after chemical cleaning when chemical cleaning was performed when the flux decreased to 50% of the initial flux.

(2) Experiments with the repeated use of cleaning chemicals indicated that the chemicals could be reused at least five times.

3.2 Pollutant removing characteristics

Table 3 shows the analysis results for water quality of membrane feed water and membrane filtrate for the period from September 1991 to March 1996. **Fig. 4** shows the relationship between the mean value and variation (standard deviation) of the removal ratio of the main pollutants that were removed by the organic membrane used in this experiment.

The results shown in **Table 3** and **Fig. 4** can be summarized as follows:

(1) Turbidity and bacteria were almost 100% removed,

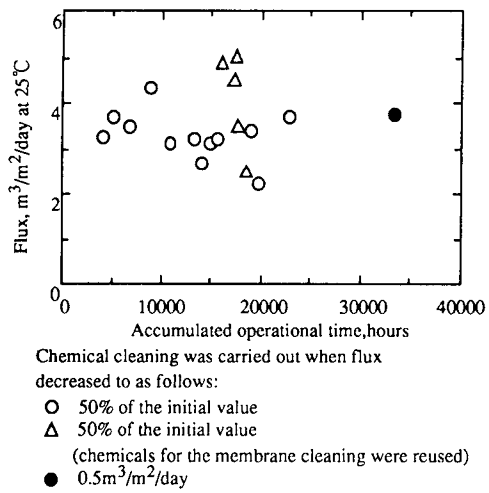

Fig. 3 Change in flux of the membrane just after chemical cleaning

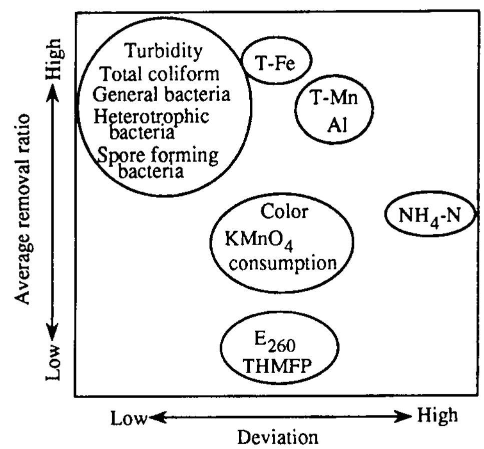

Fig. 4 Relationship between mean value and deviation of pollutant removal ratio

Table 3 Qualities of the feed water and filtrate

	Feed			Filtrate			Average removal ratio(%)
	max.	min.	av.	max.	min.	av.	
Turbidity(mg/L)	464.0	0.6	9.0	0.28	0.00	0.00	100
Color(mg/L)	65	2	6.1	7	1	3.0	57.4
SS(mg/L)	37.0	0.5	6.5	1.4	0.0	0.1	97.1
$KMnO_4$ consumption(mg/L)	7.4	1.2	3.7	3.7	0.8	2.3	37.0
NH_4-N(mg/L)	0.21	0.00	0.05	0.20	0.00	0.03	53.8
T-Fe (mg/L)	4.280	0.001	0.309	0.080	0.000	0.010	94.7
T-Mn (mg/L)	0.090	0.000	0.014	0.010	0.000	0.002	78.4
Al(mg/L)	0.790	0.006	0.242	0.441	0.000	0.059	73.1
E_{260} (-)	0.152	0.061	0.091	0.126	0.049	0.075	16.9
General bacteria(CFU/mL)	24000	570	5610	160	0.0	28.5	99.3
Heterotrophic bacteria(CFU/mL)	280000	5200	66793	7300	3.3	929	97.9
Total coliform(MPN/100mL)	110000	94	19462	54	0	2.8	100
Fecal coliform(MPN/100mL)	2200	45	502	2.9	0	0.1	100
Spore forming bacteria(CFU/mL)	180	18	57	0.10	0.00	0.01	100
THMFP(mg/mL)	0.042	0.007	0.019	0.041	0.006	0.017	14.1

and the variation in their removal ratio was small. Spore-forming bacteria, whose sterilization treatment cannot be performed easily with normal chlorine concentrations, were almost 100% removed.

(2) The removal ratio of total Fe was higher than the removal ratio of total Mn and Al, and the variation in the removal ratio of total Fe was smaller than the variation in the removal ratio of total Mn and Al.

(3) The removal ratios of $KMnO_4$ consumption, adsorption (260 nm), and THMFP, which is an index of organic substance, were relatively low at about 15% to 40%.

4. Cost analysis

Based on the pilot experiment results, a cost comparison was made between low and high flux operation. The basis for this comparison was as follows:

- Planned treated water quantity : 50000 m^3/day
- Membrane feed water : prefiltered water by automatic strainer
- Filtration mode : dead end operation without adding coagulant
- Physical cleaning interval : 30 minutes
- Operation mode : constant flow filtration operation
- Membrane life : 3 to 5 years

Table 4 summarizes the facility specifications, construction cost, and operating cost of the low and high flux operations. In **Table 4**, the construction and operating costs are expressed as relative values with the cost of low flux operation being 100. The breakdown of the operating cost is shown by a parenthesized numeral.

Table 4 Cost analysis under different flux conditions

	Low flux	High flux		
Flux	$0.5m^3/m^2$/day	$1.5m^3/m^2$/day		$2.0m^3/m^2$/day
Membrane area	$100{,}000m^2$	$33{,}000m^2$		$25{,}000m^2$
Water recovery	77.6%	91.5%		93.3%
Floor area	$7{,}200m^2$	$2{,}050m^2$		$1{,}800m^2$
Chemical cleaning cycle	1 time/year	4 times/year		8 times/year
Construction cost	100	42		35
Membrane life	5 years	5 years	3 years	3 years
Operation cost	100	39	59	48
(1)Power cost	(10.0)	(8.3)	(8.3)	(8.0)
(2)Membrane replacement	(89.6)	(29.7)	(49.6)	(37.9)
(3)Chemical cost	(0.4)	(1.0)	(1.1)	(2.1)

For low flux operation, the advantages of a decreased chemical cost and ease of maintenance are expected because of the reduced chemical cleaning frequency. However, **Table 4** shows that the high flux operation achieves a high recovery ratio, space savings, and low construction and operation costs compared to the low flux operation. In order to back up the high flux operation, it will be essential to develop a rapid cleaning technology that eliminates the need for wastewater treatment as a substitute for chemical cleaning.

5. Conclusion

The pilot experiment for the "Technical Research Committee of Yokosuka City for New Drinking Water Treatment Process" was carried out for four and a half years (a total of 40000 hours). Many results on advanced treatment were obtained including the operational and treatment characteristics of organic MF membranes. In particular, the continuous, 40000 hour, membrane treatment experiment period was the first in Japan, and it confirmed that the organic membrane used can withstand practical use.

At present, membrane filtration technology is widely being used mainly for small water systems as a substitute for coagulation-sedimentation and sand filtration. In the future, membrane filtration facilities to positively remove chlorine-resistant pathogenic parasites (e.g., *Cryptosporidium*) may increase. Further, in fiscal 1997, the "Guideline on Application of a Membrane System to Advanced Water Treatment" and the "Guideline on Application of a Membrane System to Sludge Treatment of Water Treatment Plant" will be prepared based on the results obtained from the advanced treatment MAC 21 project, and the adoption of a membrane treatment facility to a relatively large-scale waterworks is expected. NKK intends to continue technical development for securing "safe and tasty water."

We wish to express our thanks to Dr. M. Tanbo, President of Hokkaido University, Prof. Dr. Y. Magara of the Institute of Public Health, Prof. Dr. S. Kimura of Osaka University, Prof. Dr. M. Kaneko of Setsunan University, and concerned personnel at the Waterworks Bureau of Yokosuka City for their advice and cooperation in carrying out this study.

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Complex Industrial Waste Treatment Facility for Toyota Motors Corporation

1. Introduction

The ever-increasing volume of waste has become a serious social concern, and effective uses for waste are needed. Various recycling technologies have been developed and used in practical applications that include the reuse of containers such as bottles, cans and packaging materials, waste-reclamation through drying waste and selecting combustible materials to produce a solid fuel (RDF), and plastics-to-oil conversion systems that sort waste plastics and convert the effective materials into liquid fuel. These development activities have brought waste treatment to a turning point for creating a recycling society.

Japan is surrounded by oceans, and the incineration of waste is still the most important technique from the viewpoint of reducing the volume, stabilizing the residuals, and preventing pollution. Incineration reduces the volume of waste to ash by one twentieth. Accordingly, incineration is a superior method for processing waste.

Along with the promotion of pollution-prevention and heat-utilization in municipal solid waste treatment systems, progress has also been made in the high grade treatment of industrial waste. This paper introduces a complex industrial waste treatment plant that was constructed for Toyota Motors Corp. at the end of July 1997 (**Photo 1**). The core of the facility is an NKK fluidized bed incinerator (**Fig. 1**) that simultaneously treats various kinds of industrial waste and effectively uses the heat generated from incineration. The plant achieved a high pollution-prevention standard that is comparable to the level of most advanced municipal solid waste treatment plants.

2. Outline of facilities

The Environmental Center of Toyota Motors Corp. has a fluidized bed incinerator that treats coal and waste together. The incinerator can treat 216 t/d and generate 16 MW of power. The center also has two 60 t/d, rotary kiln, waste sludge incinerators. In addition, Toyota Motors Corp. planned and ordered a complex industrial waste treatment plant based on a fluidized bed incinerator (**Table 1**).

The plant comprises a waste oil and liquid treatment facility, a fluidized bed incinerator, a waste liquid incinerator, and auxiliary facilities (**Fig. 2**).

3. Characteristics of individual facilities

3.1 Waste oil and liquid treatment facility

The facility receives waste oil and liquid discharged from various plants and separates it into waste sludge, combustible waste oil, and waste liquid. The facility has a capacity of 9 m^3/h.

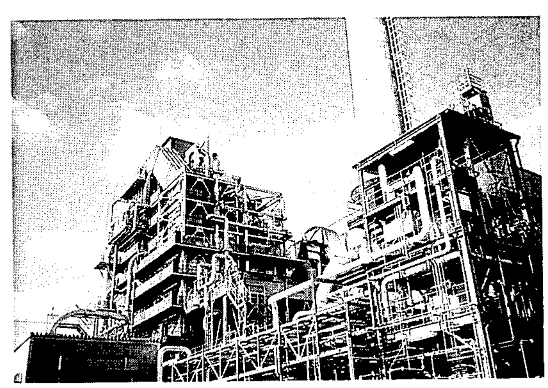


Photo 1 Overall view of the plant

Waste oil and liquid are unloaded from dump trucks, pass through a vibrating screen to remove foreign materials (iron chips, plastics, etc.), and then enter the waste oil and liquid receiver tanks. The waste oil and liquid is then pumped from the waste oil and liquid receiver tanks to heat exchangers, where they are heated by boiler steam to reduce their viscosity. The heated waste oil and liquid then enter separators that divide the waste oil and liquid into waste sludge, combustible waste oil, and waste liquid using differences in specific gravity. The recovered combustible waste oil is used as a high grade fuel for burner combustion.

After separation, the liquids are stored in separate tanks. Waste sludge is incinerated in the fluidized bed incinerator along with waste sludge from the waste water treatment process. Combustible oil and waste liquid are treated either in the fluidized bed incinerator or in the waste liquid incinerator. The combustible oil is also used as a fuel for the waste sludge incinerator.

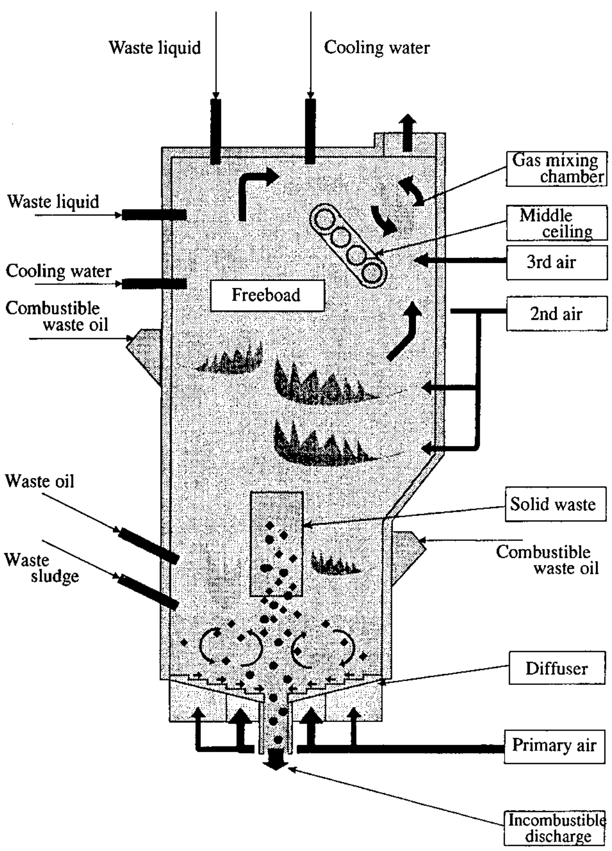


Fig. 1 NKK fluidized bed incinerator

3.2 Fluidized bed incinerator

The fluidized bed incinerator treats 159.6 t/d of solid waste (waste plastics, etc.), waste sludge, combustible oil, waste oil, and waste liquid. Heat is recovered as steam.

Solid waste, such as waste plastic, is charged from transportation vehicles onto conveyers, which are equipped with metal detectors. After that the waste is crushed and temporarily stored in pits before being incinerated. The combustible oil and waste liquid is charged either directly above the fluidizing bed in the lower part of the furnace or from the freeboard, depending on the combustion state in the furnace.

The incinerator is controlled by a distributed control system (DCS). An automatic combustion control unit is also installed to provide adjustment over a wide range of combustion volumes in response to variations

Table 1 Plant specification

Item	Specification
Solid waste receiving and feeding facility	Pit and crane system Full automatic crane Crasher(15t/h: 1, 5t/h: 1) Crasher feeding conveyor (with metal detector)
Waste oil and liquid treatment facility	9m^3/h Centrifugal separator(6m^3/h:1, 3m^3/h:1)
Fluidized bed incinerator	159.6t/24h
Boiler	18.3t/h, 2.25MPa(23kg/cm^2)
Flue gas treatment facility	Dry lime + Bag filter Non catalytic denitrification
Fly ash treatment facility	Solidification with cement (with chemical dosing)
Waste liquid incinerator	48t/24h
Control system	DCS Automatic combustion control
Safety facility	Wire rope switch Photo tube switch Safety plug and safety switch
Pollution control	HCl 80ppm(12%O_2) SO_2 175ppm NOx 95ppm(12%O_2) CO 50ppm(12%O_2) Dust 30mg/Nm^3
Construction term	March 3 '95 ~ June 30 '97

in the volume of waste, which are caused by car production facility operating conditions, and to maintenance requirements for the existing waste incineration plants.

The fluidized bed incinerator achieved a high standard of pollution prevention that is equal to or better than the level of most advanced municipal solid waste incineration plants because of the use of combustion control, non-catalytic intrafurnace denitrification using urea-water, dry lime injection, and bag filters.

3.3 Waste liquid incinerator

The waste liquid incinerator treats 43 t/d of waste liquid by the submerged combustion method. The incinerator operates when the other furnaces are shut down.

The flue gas emitted from the furnace is treated by a cooling vessel using aqueous sodium hydroxide, intrafurnace non-catalytic denitrification, and a venturi scrubber. The pollution prevention standard attained is a high level that is similar to that of the fluidized bed incinerator.

3.4 Facility safety

The plant has a high level of safety features that conform to the in-house standard of Toyota Motors Corp. All of the wire-rope switches located in the peripheral area of the conveyers, photocell switches, and fence gates that separate dangerous areas, such as those for rotating machinery, have a "three-device set safety unit" (that is, the gate does not open unless a door key, an emergency stop switch, and a safety plug are all released).

4. Conclusion

The constructed industrial waste treatment plant reduces the volume of various kinds of waste with a minimum of pollution, while recovering heat. The plant provides Toyota Motors Corp. with efficient energy recovery with low environmental impact using the combination of existing incinerators.

In response to customers' needs that range from municipal solid waste to industrial waste, NKK has developed a wide variety of technologies for waste volume reduction, pollution prevention, and heat utilization.

We would like to express our appreciation to the staff of Toyota Motors Corp. for their cooperation in the planning, design, construction, and testing of the plant.

Please refer to:
Environmental Plant Engineering and Design Dept.
Hajime Akiyama

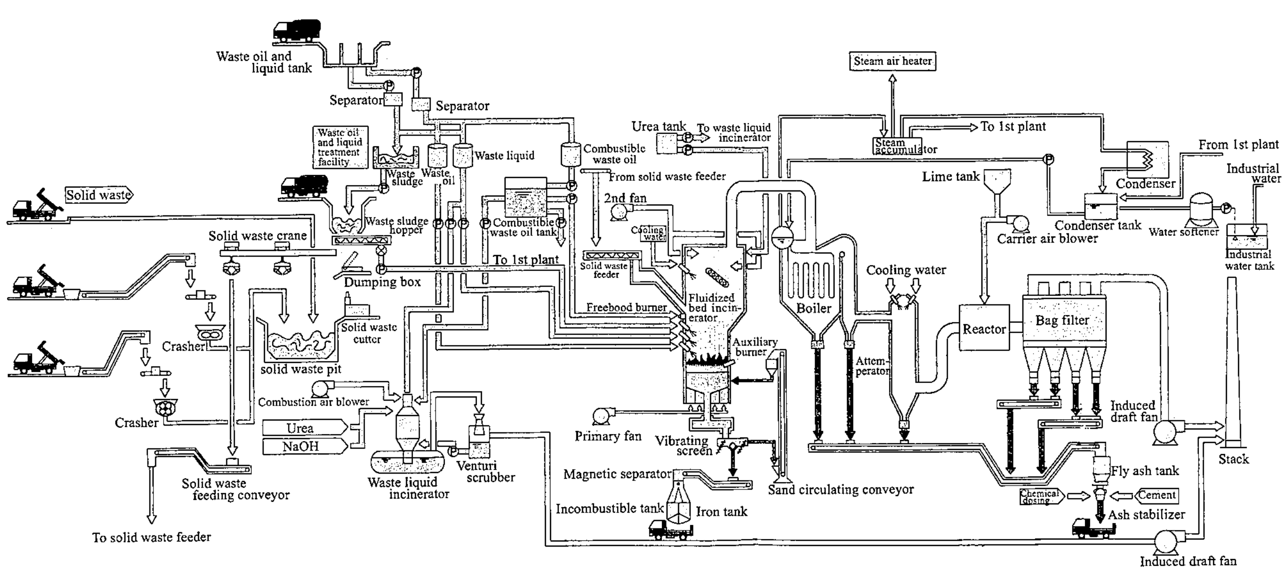


Fig. 2 Plant flow chart

High Temperature Gasifying & Direct Melting Process of Solid Waste

1. Introduction

New technology for waste treatment has been increasingly anticipated, not only to reduce the volume for pollution treatment, but also to enhance material utilization and increase energy recovery as electric power. To meet these expectations, NKK started the development of a gasifying and direct melting furnace in 1992 as next-generation waste treatment technology, in which non-combustibles in the waste are made into molten slag to enhance material usefulness, while combustibles are used as gaseous fuel.

A pilot plant (**Photo 1**) with a treatment capacity of 24 t/day was built at NKK's Tsurumi Works in 1995. Long-term operation was carried out by treating various kinds of wastes, and technical development was completed.

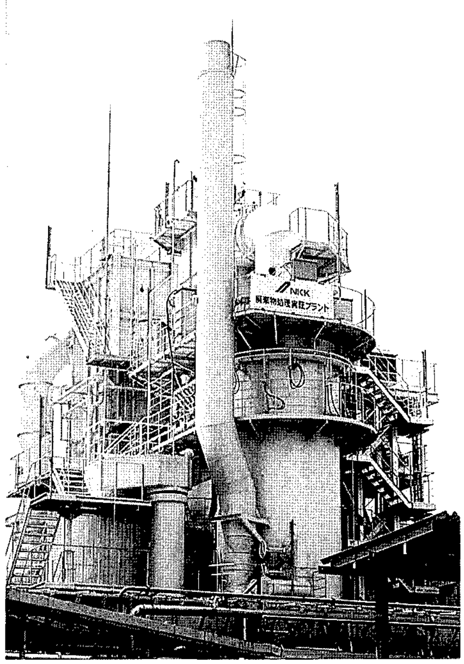


Photo 1 Pilot plant

This report describes the principle of this technology and summarizes the features demonstrated by this pilot plant.

2. High-temperature gasifying and direct melting technology

2.1 Principle

Fig. 1 is a schematic diagram of a high-temperature gasifying and direct melting furnace.

This furnace uses a new technology that combines NKK's blast furnace technology and fluidized bed technology for refuse incineration. The furnace body is composed of three zones: a high-temperature combustion melting zone with a lower moving bed, a fluidized bed dry distillation zone, and a freeboard, in which the product gas is maintained at a high temperature.

Solid waste is fed from the upper part of the furnace with coke, which is an auxiliary fuel, and lime, which is used to control basicity into the dry distillation zone. The temperature of this zone is kept at about 700°C by air supplied through some sub-tuyeres, so that the solid wastes are rapidly heated and dry-distilled while being agitated. Problems such as the plastic materials fusing to each other can be avoided. Volatile matter flies up to the freeboard, and dry distillation residues containing non-combustibles sink to the lower layer together with coke and lime.

In the high-temperature combustion melting zone, fixed carbon and coke are burned at high temperature by air enhanced with oxygen. The air is supplied through some main tuyeres, and the incombustible materials are melted by the heat. The molten material sinks to the furnace bottom and is discharged from the furnace through a notch after the slag and metal are separated from each other by the difference of their specific gravity in the slag/metal bath.

The product gas is maintained as a reducing atmosphere at 1000 °C in the freeboard by air supplied through some No. 3 tuyeres. It is then discharged from the furnace as a combustible gas.

2.2 Process applications

Two process configurations are possible for this technology. In one, the gas produced from the melting furnace is used as a fuel after gas treatment, while in the other, the product gas is burned in a secondary combustion furnace, and the waste-heat is used.

The configuration that uses the product gas as a fuel can be further classified into two types. In the fuel recovery GTCC system, electric power is generated using the product gas as fuel for a low BTU gas turbine, as shown in **Fig. 2(a)**. In the fuel recovery BTG system, electric power is generated using the product gas as fuel for a high-temperature and high-pressure boiler, as shown in **Fig. 2(b)**. The system that uses the gas directly as a fuel requires a small quantity of gas, so that the scale of the gas treatment equipment can be made small. Further, since the product gas is used as a fuel, the power generating efficiency can be increased significantly.

A heat recovery boiler system is also available, as shown in **Fig. 2(c)**. In this system, although the gas quantity is more than in the previous processes, complete combustion can be accomplished with a lower excess air ratio than that of a conventional incineration system. Thus, a higher power-generating efficiency can be expected compared to a conventional

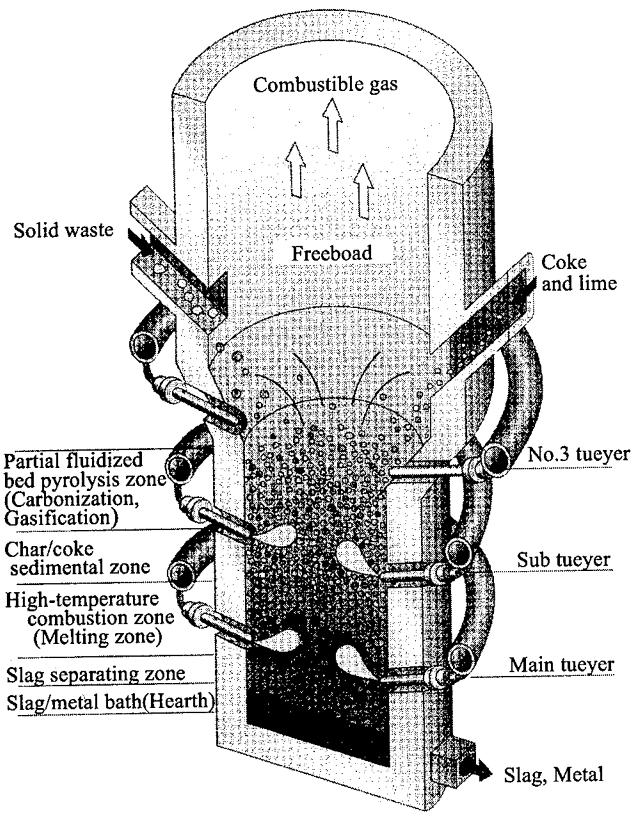
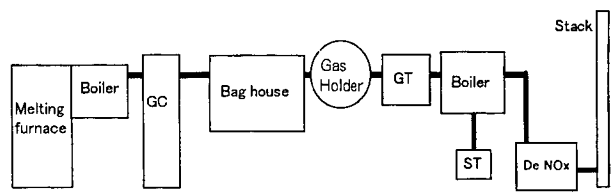
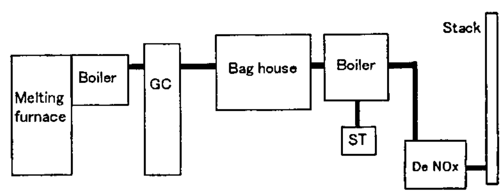


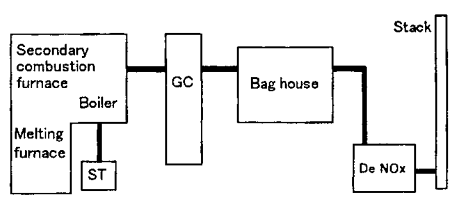
Fig.1 High-temperature gasifying and direct melting furnace



(a) Fuel recovery GTCC system



(b) Fuel recovery BTG system



(c) Heat recovery BTG system

Fig.2 Energy recovery system

waste heat boiler.

3. Results of proof test

Long-term operation was performed using a pilot plant with a treatment capacity of 24t/day.

Table 1 gives the composition of gas at the melting furnace outlet when wastes are treated. The combustibles in the product gas consist mainly of carbon monoxide and hydrogen. This gas has good handling properties because of its low tar content. Also, the hydrogen chloride generated from the furnace reacts with lime to yield calcium chloride, so that the HCl concentration can be kept as low as 50 ppm or lower.

The concentration of dioxin at the secondary furnace outlet is 0.20 ng-TEQ/Nm³, as shown in **Table 2.** Since the furnace interior has a high-temperature reducing atmosphere, the generation of dioxin is kept at a low level.

Table 3 gives the composition of discharged molten slag. The content of metals in the slag is very low. As shown in **Table 4**, it was confirmed by a method complying with Environmental Agency Notification No. 46 that the leaching concentration satisfies the environmental standard for soil. Also, a physical strength test (JIS A5015) was made. As a result, the molten slag was confirmed to be effective as a useful raw material because it meets the standards for steel slag for roads (e.g., specific gravity of dry surface, water absorbing ratio, and corrected CBR).

4. Features of high-temperature gasifying and direct melting technology

The features of this technology are summarized as follows:

(1) Ash in the waste can be recovered without leaching heavy metals to produce a completely harmless slag

Table1 Composition of product gas (Melting furnace)

CO	%dry	29
CO_2	%dry	9
H_2	%dry	6
H_2O	%wet	6
CH_4	%dry	2
HC	%dry	0.5
	mg/Nm^3	250
HCN	ppm	140
NH_3	ppm	190
NO_x	ppm	10
HCl	ppm	10
H_2S	ppm	19
COS	ppm	10
CS_2	ppm	2
SO_x	ppm	1
Low calorific value	MJ/Nm^3	5.3
Gas temperature	K	1300

Table 2 Composition of exhaust gas (Secondary combustion furnace)

CO	ppm	16
NO_x	ppm	39
SO_x	ppm	25
HCl	ppm	10
DXN	ng-TEQ/Nm^3	0.2

Table 3 Composition of molten slag

SiO_2	%dry	41.4
CaO	%dry	34.8
Al_2O_3	%dry	2.8
MgO	%dry	1.6
FeO	%dry	1.1
Cr_2O_3	%dry	0.3

Table 4 Leaching test results of slag

Component	Leaching concentration mg/*l*	Standard value mg/*l*
Alkyl Hg	<0.0005	Non-detect
Total Hg	<0.0005	≦0.0005
Cd	<0.005	≦0.01
Pb	<0.005	≦0.01
Organo-phosphorus	<0.01	Non-detect
$Cr6^+$	<0.05	≦0.05
As	<0.005	≦0.01
Se	<0.005	≦0.01
CN	<0.02	Non-detect
PCB	<0.0005	Non-detect
CCl_2-CHCl	<0.002	≦0.03
CCl_2-$CHCl_2$	<0.0005	≦0.01

that has a high mechanical strength, so that it can be used as a road bed material. Further, the only discharged matter that requires final treatment is the ash collected as dust, and the volume can be reduced to 1/200.

(2) The high-temperature combustion in a reducing atmosphere of the melting furnace prevents even small quantities of harmful substances such as dioxins from production, and as the result the process is non-polluting and hardly affects the external environment.

(3) The combustibles in waste can be recovered as a combustible gas with good handling properties because of its low tar content. Therefore, this process can be combined with an energy recovery process that provides a high electric power conversion ratio, such as a gas turbine.

(4) Coke is used as an auxiliary fuel, and wastes are gasified at the fluidized bed portion in the furnace. Therefore, all kinds of wastes, from those that scarcely contain combustibles to those with many plastic materials, can be treated consistently without problems, and extensive waste treatment can be performed.

(5) Since the gasifying and melting reactions of wastes can be carried out in one furnace, construction is simple and compact.

5. Concluding remarks

High-temperature gasifying and direct melting is a new technology that can not only recover a large amount of electric power, but also meet the needs for a recycling society. In the future, therefore, the use of this technology in the waste treatment field is expected to increase.

Please refer to:
G-Development Project Team, Engineering Research Center
Tsuneo Matusdaira
Sunao Nakamura

Waste Recycling System

1. Introduction

In Japan, as elsewhere, the volume of waste has been increasing annually, and in recent years it has been increasingly difficult to find new sites for waste-processing facilities and for the final disposal of waste. These considerations, combined with recognition of pollution problems associated with incineration, have raised people's awareness of the urgency and importance of adopting measures to address the waste-related issues. Fortunately, however, in recent years progress has been made in developing the infrastructure necessary for a waste-recycling society that incorporates environmental considerations, triggered by the phased implementation of Japan's Packaging Waste Recycling Law, which went into effect in April 1997. As a result of the above, the demand for waste-recycling technology is increasing faster than ever. In response to this demand, NKK has developed an automated system for high-speed sorting and recovery of recyclable waste.

2. Features of the system

The system has the following features.

(1) Fully automated.
(2) Processes recyclable wastes at high speed.
(3) Enables various types of waste — such as steel cans, aluminum cans, glass bottles, and plastic bottles — to be separated for subsequent recycling.
(4) Incorporates a high-performance bottle-sorting process that permits high-volume, high-speed, and accurate sorting of bottles according to color.
(5) Flexible and capable of being modified according to the specific conditions (waste-recovery methods, types and volumes of waste, and so forth) of particular municipalities.
(6) Permits sophisticated sorting of various types of plastic and removal of PVC (polyvinyl chloride).

3. Outline of the system's components

3.1 Bag breaker

As shown by **Fig. 1**, the bag breaker consists of (a) two rotating disks, each with a series of blades equally spaced around the disk's periphery, that pull bags apart and tear them open in such a way that the contents of the bag are removed without being damaged; and (b) a device that removes the torn bags.

3.2 Equipment to remove nonrecyclable-materials

This equipment removes any waste items that, because of their being too large or too small, are unsuitable for recycling by this system. The thickness of the layers of the recyclable waste remaining after such removal is controlled to facilitate sorting in the subsequent processes.

3.3 Compressed air sorter

This component uses compressed air blast to sort waste materials into three types according to their weight (heavy, medium, light). The operation of the sorter is shown by **Fig. 2**.

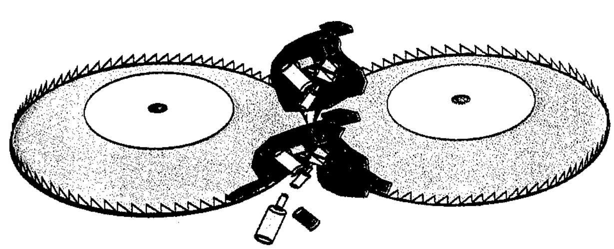


Fig. 1 Bag breaker mechanism

3.4 Round items separator

The materials recovered in the nearest chute (i.e., the heaviest items) by the compressed air sorter are then separated by their shape into two categories: (1) round glass bottles, which are recyclable, and (2) glass and ceramic materials that are unsuitable for recycling. The latter materials are then removed.

3.5 Color-based glass-bottle sorter

The color-based glass-bottle sorter consists of a sizer, a conveyor, a color detector, and a deliverer. The configurations of the sizer and color detector are shown by **Figs. 3** and **4**, respectively. The sizer sorts glass bottles recovered by the round items separator into four categories according to size (very large, large, and small bottles, and glass fragments), in order to improve the efficiency of the color-based glass-bottle sorter. The equipment's internal materials-conveyor uses a combination of vertical and horizontal belts to move bottles at a fixed-distance interval. The color detector uses the combination of a proprietary lighting system to illuminate the base of each bottle and a CCD camera to capture an image of the diffracted and transmitted light, which is then analyzed and processed by the detector's CPU to sort the bottles into six categories according to color (transparent, brown, green, blue, black, and other) without the process being interfered with by a bottle's label.

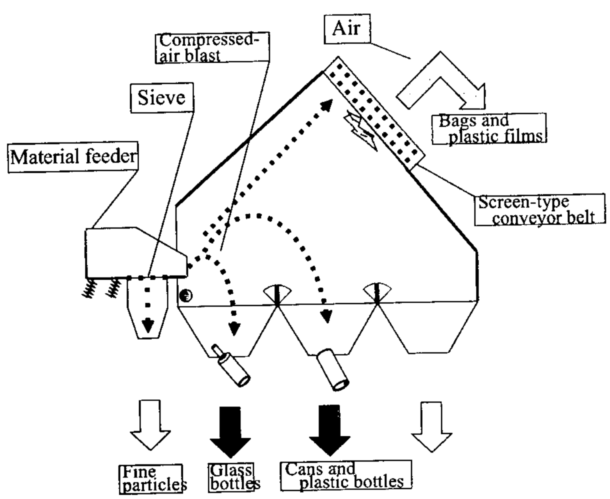


Fig. 2 Operation of the compressed air sorter

3.6 Plastic sorter

Identification of the material type of plastic objects is made by use of centrifugal and optical methods (See **Fig. 6**).

3.6.1 Centrifugal plastic sorter

Centrifugal force is used to separate plastic objects in water according to the specific gravity of the objects' constituent materials. This method is used for plastic films, primarily to remove PVC. **Fig. 5** illustrates this process in detail.

3.6.2 Optical plastic sorter

X-rays and near-infrared radiation are used to separate items according to the material type of plastic objects. This method is particularly useful for separating plastic bottles of various shapes.

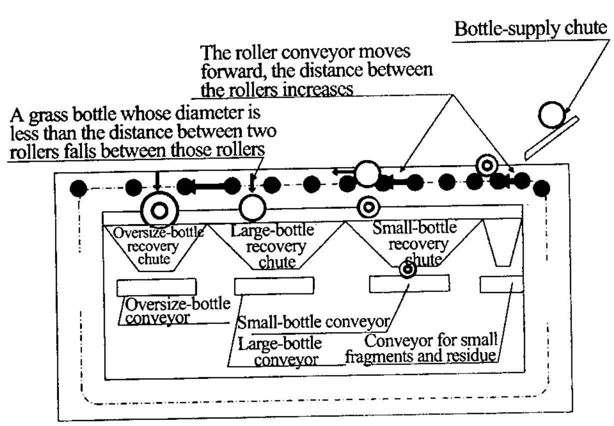


Fig. 3. Glass-bottle sizer

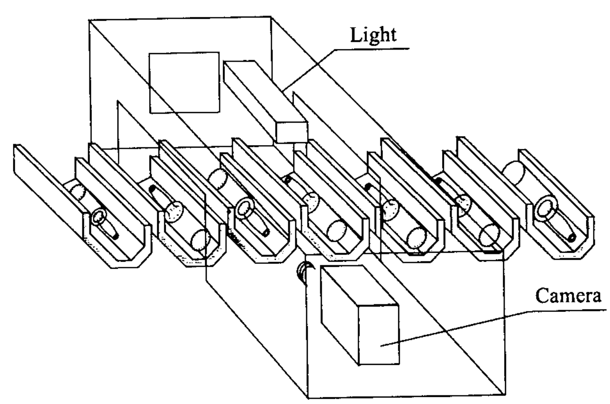


Fig. 4. Glass-color detector

4. System flow

The flow of materials in the overall system is shown by **Fig. 6**. The flexibility of the system allows the flow to be changed to accommodate the requirements of each municipality.

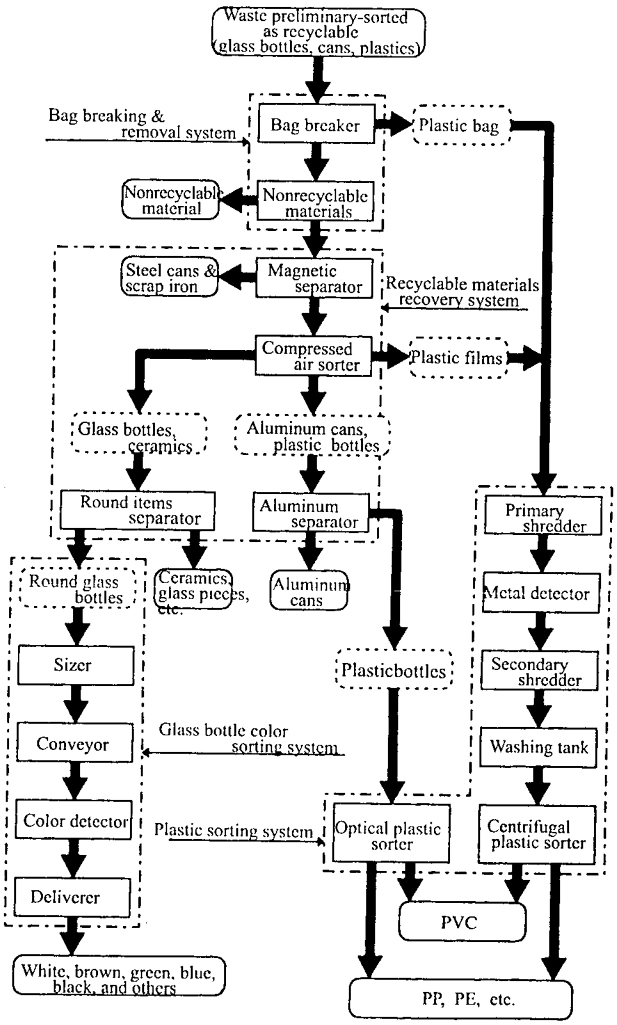


Fig. 6 System flow

5. Existing and future facilities

The construction of recycling facilities was completed at NKK Environmental R&D Center in Tsurumi City, Kanagawa Prefecture (processing capacity: 30 tons/5 hours), and in Haga County, Tochigi Prefecture, (processing capacity: 12.5 tons/5 hours) in April 1996 and March 1997, respectively. The latter facility, which was created for the Haga County Central Region Environmental Hygiene Association, is being used to separate and recycle a mixture of glass bottles, cans, and PET bottles. **Fig. 7** shows the layout of that facility's equipment. NKK has received orders to create other recycling facilities, construction of which will begin in the near future.

Please refer to:

Control Engineering Research Dept., Applied Technology Research Center
Mikisuke Asano
Engineering and Recycling Technology Center
Minoru Takuwa

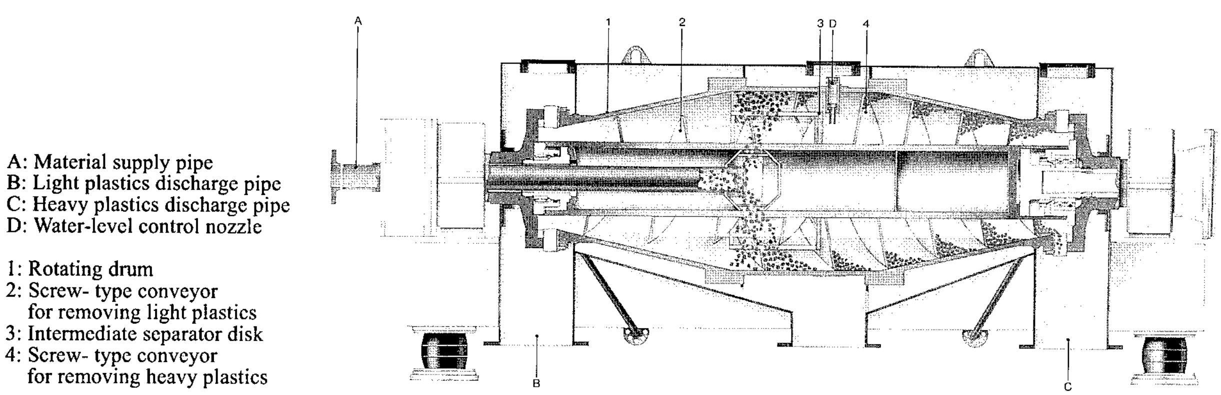


Fig. 5. Cross-section of a centrifugal plastic separation system

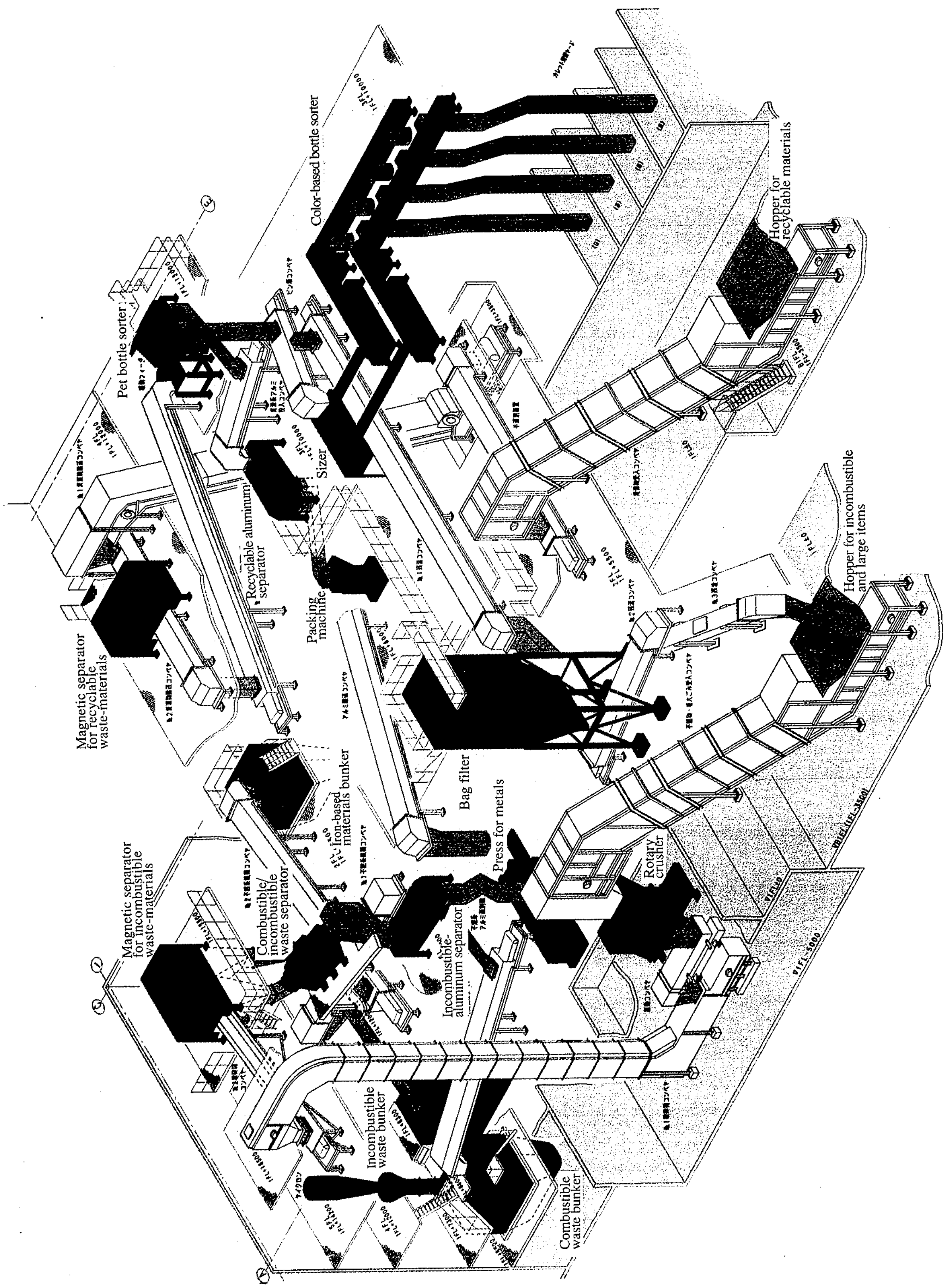


Fig. 7 Layout of equipment in the Haga Country recycling facility

Oxidation Ditch System with Submerged Propeller

1. Introduction

The oxidation ditch (OD) process is a waste water treatment method that provides easy operation, responds to load fluctuations, and removes nitrogen. Because of these advantages, the OD process has been in common use for a long time in Western countries. Many local cities in Japan have also introduced the OD process in recent years, and it has already become the most common small-scale waste water treatment plant.

NKK developed an oxidation ditch system with a submerged propeller that aimed at a higher quality of treated waste water, more efficient oxygen supply, lower operational cost, and easier maintenance than the conventional OD process. NKK conducts market development and sales for these systems.

The conventional OD process uses vertical or horizontal shaft rotors on the surface of the ditch to perform surface aeration and to agitate the waste water (generate water flow). Since the conventional OD process provides both aeration and agitation functions simultaneously using the same apparatus (rotors), it is difficult to establish optimum control of each function in response to fluctuating sewage influent loads.

Thus, our oxidation ditch system has a submerged propeller and performs aeration and agitation with distinct components to separate the ability to control each function. A diffuser system is used for aeration because it provides the highest reliability and has extensive commercial experience, while an immersed propeller is used for agitation. The propeller has a large blade span and operates at a low speed of rotation. The combination of the two different devices allows operation at an optimum condition with a minimum energy consumption under fluctuating sewage influent loads.

In response to the increasing shortage of skilled engineers for operating small, waste water treatment plants in local cities, NKK developed a DO controller called "RSC-100." This is an intermittent aeration controller that assures a fully-automatic supply of oxygen in response to fluctuations in the load of sewage influent.

2. Characteristics of the oxidation ditch system with submerged propeller

Fig. 1 shows a schematic drawing of the oxidation ditch system with submerged propeller, and **Photo 1** shows the submerged propellers and diffusers.

The submerged propeller, oxidation ditch system has the following five characteristics.

(1) Assurance of anaerobic and aerobic conditions

Since the aeration and agitation devices are provided separately, an anaerobic condition is sustained by stopping the air supply to the aeration device because the submerged propellers provide ditch agitation. Consequently, the system has a favorable performance for nitrogen removal.

(2) Easy response to load fluctuation and start-up transients

With adjustments of the interval and period of operation for the oxygen supply blower, the operation of the system is easy, even for fluctuating loads and for start-up transients, when there is a small sewage influent rate.

(3) Energy saving

The large propeller span and low rotational speed provide water flow with low power consumption. The diffuser uses diffuser disks made of a rubber membrane that generate fine bubbles and provide high oxygen-dissolving efficiency. As a result, the oxygen supply efficiency reaches 3 kg O_2/kWh, which is about 1.5 times that obtained by conventional vertical or horizontal shaft surface aeration processes.

(4) Decrease of occupied space

Compared to the 2 to 3 meters of water depth necessary for a conventional vertical or horizontal shaft surface aeration process, the submerged propeller, oxidation ditch system is used in 5 to 6 meters of water. Accordingly, the space occupied by the ditch is reduced.

(5) Diminishing large fluctuations of load of sewage influent

When combined with a float type, constant effluent rate unit, the system can change the water level in the ditch to provide a flow rate adjustment function. This function assures a constant inflow rate to the final sedimentation tank to stabilize the sludge-liquid interface and provides a favorable and stable quality of treated water.

3. DO controller "RSC-100"

Many treatment plants use intermittent aeration to prevent a decrease in the pH caused by nitrification in low load activated sludge processes such as the oxidation ditch process. Conventional control of intermittent aeration is performed by manually setting the 24 hour timer and the rotational speed of the aeration device (blower) based on trends that appear on the DO meter. Therefore, it is difficult to stabilize the operation of plants that are subjected to large weekly or seasonal load fluctuations and all plants during the start-up period. To solve this problem, NKK developed the "RSC-100" DO controller.

Photo 2 shows the appearance of RSC-100.

3.1 Principle of aeration control

Fig. 2 illustrates the control concept.

The interval time T_I is automatically set between max. 8 hours and min. 1 hour in response to the load condition. Timing for the blower stop operation is controlled to establish an optimum time ratio R_{AO} for the automatically-set interval time T_I. When the blower is operated under inverter control, the air rate is controlled to provide a DO peak around 2 mg/l.

3.2 Characteristics

DO controller "RSC-100" has the characteristics described below.

(1) Most advanced hardware and software

The hardware was developed by NKK based on an M68000 CPU from Motorola, which has an established reputation as a process controlling device. The software combines a real-time operating system with

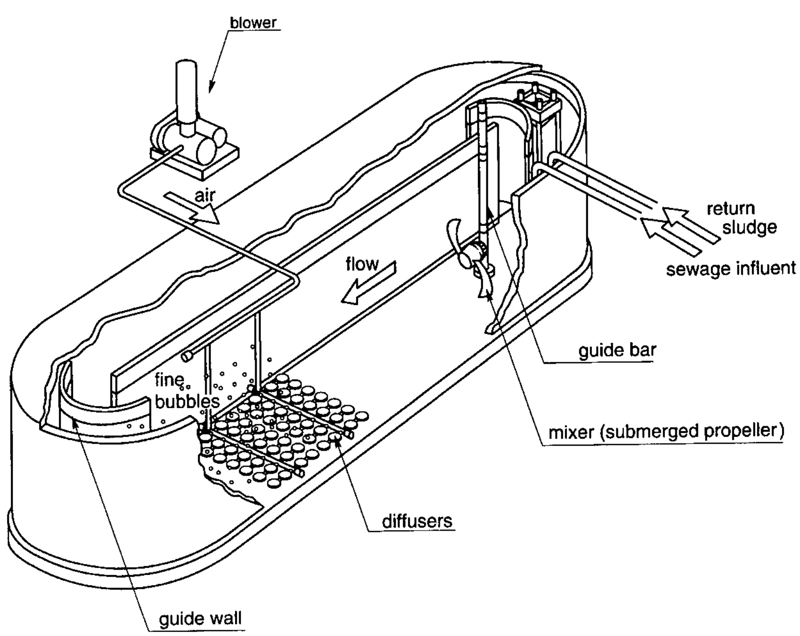


Fig. 1 Schematic drawing of the oxidation ditch system with submerged propeller

NKK original application software based on NKK's control know-how.

(2) Improved operability with liquid crystal display panel

The monitor and operation functions comprise a liquid crystal panel and push button switches. The control state is displayed by a trend-graph and a list. Various parameters can be readily changed.

(3) Full line of optional functions

Communication functions with external equipment, such as a host computer or programmable logic controller (PLC), and control functions relating to the volume of return sludge and the volume of excess sludge are available.

4. Future development

NKK has received 29 orders for the oxidation ditch system with submerged propeller. Since the system has superior performance among the various types of oxidation ditch systems that have become the mainstream type of small-scale water treatment plant, applications of the system are expected to increase.

Please refer to:
Water Treatment Plant Sales Dept.
Takeshi Watanabe
Engineering Service Section, Water Treatment Plant Engineering Dept.
Seiichi Kanamori

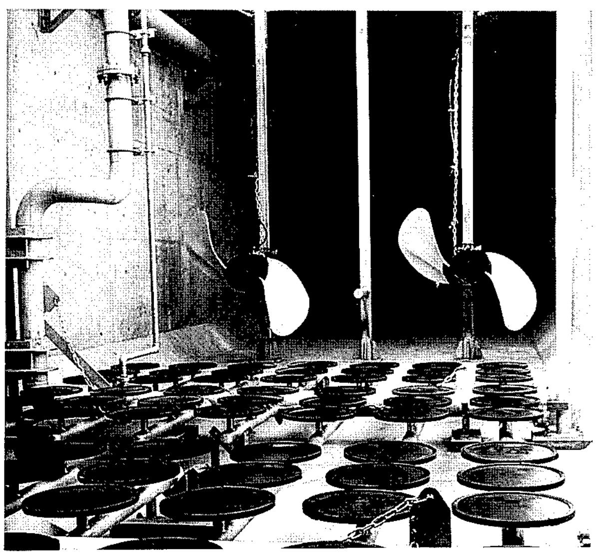


Photo 1 The submerged propellers and diffusers

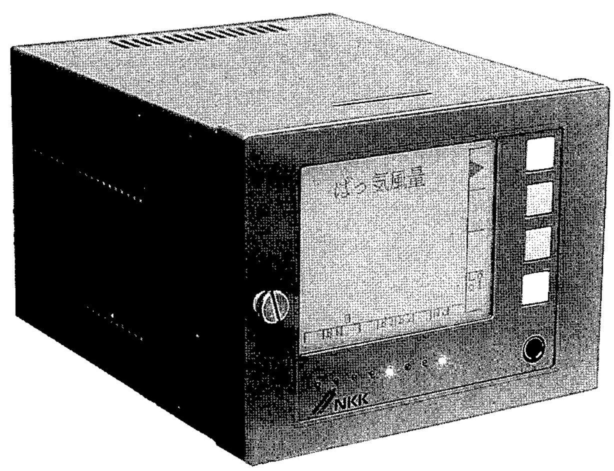


Photo 2 The DO controller "RSC-100"

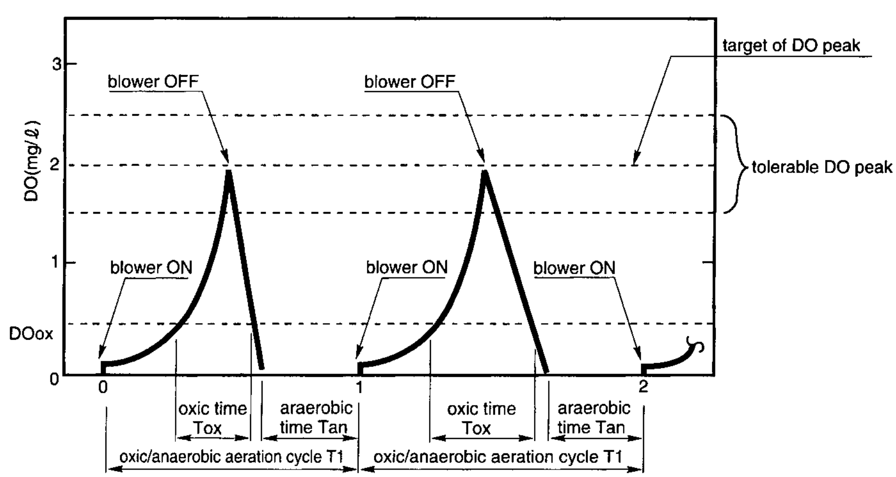


Fig. 2 The principle of the control

New Clad Pipe for Superheat Incinerator Boiler Tubes

1. Introduction

The steel pipe clad with high nickel steel introduced here was developed jointly by NKK and Daido Steel Co., Ltd. for severe corrosive environments such as that in waste incinerator boilers.

In recent years, many studies have been conducted on utilizing unused energy and on improving energy efficiency, with the aim to reduce CO_2 emissions and prevent global warming. In this respect, power generation using the waste heat from municipal solid waste incineration is a practical application for the effective use of energy. Efforts are being made to increase the steam temperature for improving the efficiency of energy utilization. Current domestic power generation at municipal solid waste incineration plants operate at steam temperatures of 300°C or lower to prevent corrosion of the superheater tubes in waste heat boilers. Most advanced facilities are designed to operate at 400°C. Although existing stainless steels resist corrosion up to a level of 400°C, high nickel steels are needed for operational conditions above this temperature. The steel pipe clad with high nickel steel was developed for this purpose.

2. Outline

Fig. 1 shows a flow chart for manufacturing the developed clad steel pipe. The mother pipe is prepared by an ordinary process. A high alloy is overlaid using the plasma process on the pipe. The overlaid pipe is then subjected to cold-working and heat treating to obtain the product clad pipe. In contrast, conventional composite pipe is manufactured by preparing inner and outer tubes separately, assembling them together using hot-extrusion, applying cold-working, and finally providing a heat treatment. The new process has fewer steps than the conventional manufacturing process, while assuring excellent performance at low cost. **Photo 1** shows the appearance and a macroscopic cross section of a prototype of the developed clad steel pipe.

3. Features

The application of a plasma overlay of a highly corrosion-resistant alloy onto a common heat exchanger tube material, followed by cold-working and heat treating makes the corrosion resistance of the clad layer equivalent to that of pipes manufactured by an ordinary hot-working process. This material has the following features.

(1) Plasma overlay assures complete joining between the clad layer and the mother material.

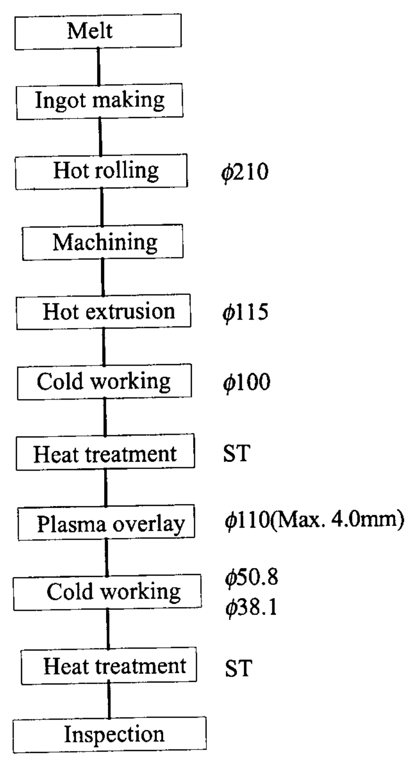


Fig.1 Manufacturing process of developed clad pipe

(2) The use of an existing material for the mother material eliminates the necessity for material approval, even when the developed corrosion-resistant material is used for the clad layer.
(3) Cold-working of an appropriate size pipe results in a pipe with a smaller diameter and longer length. In addition, the combination of the plasma overlay method, which ensures good productivity, with cold-working permits a wide range of production volumes, such as from small lots to mass production.
(4) The elimination of hot-working allows the use of materials that are difficult to hot work, providing the material accepts a plasma overlay.
(5) The cold-worked product offers a high level of quality assurance, including non-destructive inspection.

4. Corrosion resistance

Composite tubes manufactured for testing were placed in a municipal solid waste incinerator to check their corrosion resistance. The result is described below.

4.1 Manufacturing process

Overlay welding → Softening annealing(1100°C) → Pilger rolling → ST (1150°C) → Pickling

Mother pipe: $\phi 53.0 \times t10$ (7.0 + 3.0)
Product pipe: $\phi 38.1 \times t7$ (5.4 + 1.6)
Base material: Mother material SUS304 / High Ni alloy (19%Cr-13%Mo-57%Ni)

4.2 Test procedure

A test piece was placed in the municipal solid waste incinerator. The test duration was 4 months and 8 months. The metal temperature of the test piece was 480°C.

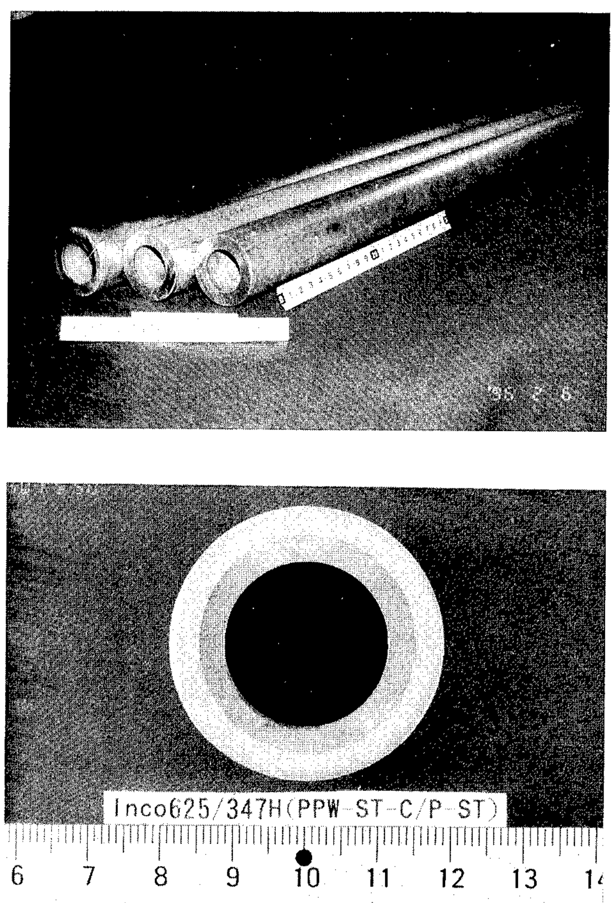


Photo 1 General and cross sectional views of developed clad pipe

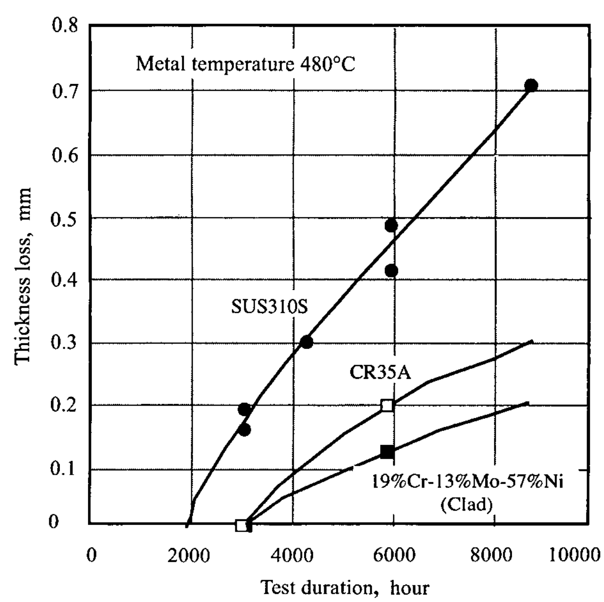


Fig. 2 Corrosion resistance of developed clad pipe produced by plasma overlay process

4.3 Test results

Fig. 2 shows the test results. The high Ni alloy clad steel pipe manufactured by plasma overlaying, cold-working, and solution annealing had corrosion resistance that was equal to or better than that of a high Ni alloy (CR35A: 35%Cr-45Ni-2Mo) produced by a common hot-working process.

5. Conclusion

The developed overlaid clad steel pipe provides excellent corrosion resistance through a new manufacturing process. It is expected that the features of the material will result in many applications over the wide variety of equipment used in high temperature environments.

Please refer to:
Pipe and Tube Technology Development Dept.,
Applied Technology Research Center
Motoaki Oyama,
Keihin Research Dept., Materials and Processing Research Center
Katsumi Masamura,

NKK CORPORATION

HEAD OFFICE
1-1-2 Marunouchi, Chiyoda-ku, Tokyo 100, Japan
Tel: 03 (3212) 7111
Cable: KOKANNK TOKYO, KOKAN JUKOO TOKYO, KOKANSHIP TOKYO
Telex: 222-2811 (NKK J), 222-2816 (NKSHIP J)

Organizations

Research and Development Division, Steel Division, Engineering Division, LSI Division, Urban Development Division, New Business Center

Research Centers

Applied Technology Research Center, Materials & Processing Research Center, Engineering Research Center

Works

Iron and Steel Works: Keihin (Kawasaki), Fukuyama
Works: Tsurumi, Tsu, Shimizu, Toyama

Overseas Offices & Affiliates

New York
NKK America Inc. New York Office
450 Park Avenue, New York, N.Y. 10022 U.S.A.
Tel: (212) 826-6250 Fax: (212) 826-6358 Telex: 233495 (NKK UR)

Houston
NKK America Inc. Houston Office
333 Clay Street, Suite 3000, Houston, Texas 77002 U.S.A.
Tel: (713) 658-0611 Fax: (713) 658-0006

Santa Clara
NKK America Inc. Santa Clara Office
2350 Mission College Boulevard, Suite 380, Santa Clara, California 95054 U.S.A.
Tel: (408) 982-8277 Fax: (408) 982-9809

Washington
NKK America Inc. Washington D.C. Branch Office
1215 17th street, N.W. Washington D.C 20036 U.S.A.
Tel:(202)467-8010 Fax:(202)452-8075

Vancouver
NKK CORPORATION Vancouver Office
P.O. Box 49168, Four Bentall Centre, Suite 3394-1055 Dunsmuir Street, Vancouver, B.C. V7X 1J1 Canada
Tel: (604) 687-0091 Fax: (604) 688-7020

London
NKK Europe Ltd. London Office
4th Floor, West Block, 11 Moorfields High Walk, London EC2Y 9DE U.K.
Tel: (071) 628-2161 Fax: (71) 638-1374 Telex: 886310 (NKK LN G) 887602 (NKK LN G)

Düsseldorf
NKK Europe Ltd.
Immermannstrasse 43, 40210 Düsseldorf, Germany
Tel: (0211) 353481 Fax: (211) 361-3589 Telex: 8587839 (NKK D)

Rotterdam
NKK Netherlands B.V.
9th Floor, Room No. 913, Calandstraat 66, 3016 CD Rotterdam, The Netherlands
Tel: (31) 10-436-13-44 Fax: (31) 10-436-14-57

Singapore
NKK CORPORATION Singapore Office
78 Shenton Way, #15-03, S-0207 Republic of Singapore
Tel: 2217277 Fax: 2244568 Telex: 21308 (NKK SP RS)

Jakarta
Jakarta Representative of NKK CORPORATION
Midplaza, 19th Floor, JL. Jend, Sudirman Kav. 10-11, Jakarta 10220, Indonesia
Tel: 5707572 / 3 Fax: (21) 5703294 Telex: 65637 (PMK IA)

Beijing
NKK CORPORATION Beijing Office
1720, Beijing Fortune Building, Chaoyang District, Beijing, People's Republic of China
Tel: 500-4375, 501-4385 Fax: 1-500-3844 Telex:210556 (NKK CN)

Hong Kong
NKK CORPORATION Hong Kong Office
402 Fairmont House, 8 Cotton Tree Drive, Central, Hong Kong
Tel: 810-0604 / 0595 / 4218 Fax: 810-4262 Telex:802-83003 (KOKAN HX)

Bangkok
NKK CORPORATION Bangkok
11th Floor, Ramaland Building 952 Rama IV Road, Bangrak. Bangkok 10500, Thailand
Tel:(2)632-9270 Fax:(2)632972

NKK

NKK CORPORATION